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Faculdade de Ciências

Departamento de Biologia Animal

Seafood consumption in Portugal: Patterns, drivers and sustainability

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Comer é uma celebração da morte ou, o que vem dar ao mesmo, um consumo da vida. Outros seres, vegetais ou animais, morrem para que nós continuemos vivos.

O mais das vezes as mortes que comemos vêm disfarçadas em filetes e bifes, em croquetes e lombinhos, distanciando-nos das matanças que foram necessárias. E essas matanças seguem-se a métodos de criação que são já uma espécie de morte e a negação de um mínimo de alegria de vida aos pobres bichos, sejam frangos, vitelos ou salmões de viveiro.

Se quiser manter a sanidade gastronómica terá de lembrar-se que todas estas manobras são recursos e imaginações, pensadas para suprir a falta de alimentos frescos, preservando os velhos e arranjando estratégias de reconstituição. A maneira como os portugueses, acima de todos, cozinham o bacalhau seco é uma das mais gloriosas excepções, já que o bacalhau fresco e acabado de morrer, por muito bem que seja cozinhado, é sempre mais desinteressante.

O nosso bacalhau (e o basco) é uma solução genial ao problema que é: não tens dinheiro para comprar peixe fresco; ou moras no interior; ou não há praça decente; mas gostarias à mesma de comer peixe ou coisa parecida. É genial porque, mesmo no país europeu com a melhor costa de pesca, implicou atravessar o Atlântico, sofrendo horrores, para ir buscar um peixe americano que se prestasse ao sol e ao sal de Portugal, de modo a podermos dispor dele quando quiséssemos.

Neste momento, porém, peço-vos que comparem uma (ou 9) sardinhas assadas, acabadinhas de pescar e grelhar, com uma lata de boas sardinhas de conserva; um caldo de peixe japonês feito a partir de pó desidratado de sardinhas; umas sardinhas descongeladas comidas quando não se consegue esperar pelos Santos.

As sardinhas frescas são melhores, desculpem lá. A bem ver, só existem, em plenitude, durante escassos 30 dias por ano. Mas são deliciosas e baratas e definidoras. Para mais, atingem o auge quando os pimentos e a alface coincidem e o clima mais se presta à degustação. São um cúmulo.

…

As coisas são melhores quanto mais depressa se estragam. Ou seja: se comer é uma celebração da morte em nome da vida; a pressa com que as comidas se degeneram é directamente proporcional à bondade delas.

Extraído de *Em Portugal não se come mal* de Miguel Esteves Cardoso

Eating is a celebration of death or, what comes to the same thing, consuming life. Other beings, plants or animals die so that we may keep on living.
Most often death comes disguised as fillets and steaks, into croquettes and tenderloin, distancing us from the necessary killings. And these killings follow already a kind of denial of life and a minimum of joy of life to the poor critters, as chickens, calves or farmed salmon.
If you want to keep any type of culinary sanity you must remember that all these manoeuvres are resources and imaginations, designed to address the lack of fresh foods, preserving the old and arranging replenishment strategies. The way the Portuguese, above all, cook dried cod is one of the most glorious exceptions, since fresh cod just after his death, no matter how well it is cooked , it is always more unattractive.
Our cod (and Basque) is an ingenious solution to the problem: you have no money to buy fresh fish; or you live inland; or there is no decent market; but you would like anyway to eat fish or something similar. It's genial because even in the European country with the best shore for fishing, it meant crossing the Atlantic, suffering horrors, to catch an American fish that would then lend itself to Portuguese sun and salt, so that we can have it whenever we want it.
Now, let me ask you to compare one (or 9) grilled sardines, coming straight from the sea with a can of sardines canned good; a Japanese fish broth made from dried sardines powder; sardines frozen when you cannot wait for the Saints festivities.
Fresh sardines are best, excuse me. In truth they exist in abundance for only 30 days a year. But they are delicious and cheap. Moreover, they reach their peak at the same time as peppers and lettuce and when the weather inspires us to better tasting food. They are a must.
...
Things are better the faster they get rotten. Meaning: if eating is a celebration of death in the name of life; the speed of food degenerating is directly proportional to their goodness.

Extract from *Em Portugal não se come mal* by Miguel Esteves Cardoso

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Resumo

O consumo de pescado está a aumentar devido ao crescimento da população mundial e ao facto de os consumidores preferirem cada vez mais peixe. No entanto as capturas da pesca têm vindo a diminuir, devido a restrições provenientes da gestão dos stocks e dos impactes ambientais da pesca. No entanto as capturas da pesca têm vindo a diminuir devido a restrições provenientes da gestão dos stocks e dos impactes ambientais da pesca. O aumento no consumo de pescado tem sido possível através da produção de aquacultura que no entanto, está dependente do peixe selvagem para rações e óleo de peixe, e interfere no funcionamento dos ecossistemas. Portugal tem um dos consumos de pescado per capita mais elevados do mundo e neste cenário é importante entender como é que a procura dos consumidores afecta a cadeia de abastecimento e de que forma pode ser alterado para um consumo mais sustentável.

Os consumidores devem estar informados sobre as consequências das suas escolhas em relação ao pescado e a sua responsabilidade no final da cadeia de abastecimento. No entanto, precisam de ferramentas que os ajudem a decidir. Apesar das iniciativas existentes, a produção de pescado continua a ser um assunto complexo para o entendimento dos consumidores. A Análise do Ciclo de Vida (ACV) é uma metodologia importante para utilizar quando há necessidade de quantificar e agregar os impactes ambientais da produção de alimentos, como o pescado. No entanto, a área do consumo sustentável requer investigação interdisciplinar e estudos com consumidores, de forma a caracterizar os hábitos de consumo e a encontrar formas de comunicação eficientes e adaptadas ao contexto. Os principais objectivos da tese foram descrever o consumo de pescado em Portugal, aplicar a metodologia de (ACV) para produtos do mar portugueses, e descobrir como comunicar com os consumidores para melhorar a sustentabilidade.

O primeiro estudo da tese teve como objectivo responder à questão porque é que os portugueses têm um consumo de pescado muito elevado e acima da média europeia. Para identificar os motivos e possíveis consequências desse consumo foi feita uma análise das estatísticas nacionais e uma revisão bibliográfica sobre o consumo de pescado em Portugal ao longo do tempo. Em países costeiros espera-se um maior consumo de pescado devido à grande diversidade de produtos disponíveis, mas o consumo de pescado em Portugal não está apenas relacionado com a geografia, pesca, ou disponibilidade de recursos marinhos; está também com outros factores como a influência da religião e da política nos hábitos alimentares. Comparando com outros países Europeus, o consumo de pescado em Portugal é caracterizado por uma elevada diversidade de espécies mas o bacalhau é a espécie mais importante nos hábitos alimentares. Representa aproximadamente 40% do pescado consumido em Portugal. Apesar de ser um peixe que não existe na costa Portuguesa, factores como a religião e as tradições, promoveram o seu consumo ao longo do tempo. O elevado consumo tem consequências ambientais e económicas, uma vez que é fornecido a partir de outras partes do mundo, onde o pescado pode ter um papel importante na segurança alimentar local, ou de stocks que não se tem conhecimento suficiente. Além disso, o elevado consumo de pescado impõe riscos de saúde relacionados com ingestão de substâncias tóxicas, mas não existe uma recomendação sobre o assunto para Portugal.

Entre o pescado mais consumido pelos portugueses, a sardinha é o peixe mais importante em termos de capturas. A pesca da sardinha foi avaliada com ACV para identificar os impactes ambientais da frota de cerco. Variáveis como o tamanho dos barcos e tempo foram verificadas e utilizadas categorias de impacto ambiental específicas para a pesca para complementar a análise com informação biológica. A pesca do cerco tem menores impactes ambientais em relação a outras pescarias devido ao baixo consumo de combustível e a menores impactes biológicos, devido ao comportamento dos peixes pelágicos de se agruparem em cardumes. No entanto as devoluções das capturas acessórias podem ser substanciais e é necessário gestão do stock. Foram encontradas diferenças no desempenho ambiental da pesca entre anos, e a variabilidade pode ser ainda maior entre meses. Verificou-se que mesmo que uma pescaria seja eficiente, há necessidade de verificar o

estado do stock. Para além disso não foram encontradas diferenças no uso de combustível entre embarcações grandes e pequenas, apesar da composição das capturas ser diferente.
Pequenos peixes pelágicos, como a sardinha, têm capturas com grandes volumes que são difíceis de processar. A indústria conserveira Portuguesa tradicionalmente utiliza este tipo de pescado e o produto mais importante, as conservas de sardinha em azeite, foi avaliado com a metodologia ACV. O caso de estudo foi um produto de uma fábrica de conservas que usa o método tradicional. O desempenho ambiental das sardinhas em conserva foi analisado e comparado com outros produtos, como sardinhas congeladas e refrigeradas. Entre os diferentes produtos de sardinha, a melhor escolha para o ambiente seria sardinhas refrigeradas, apesar de que as sardinhas congeladas não representarem uma grande diferença. O custo ambiental de sardinhas em conserva é quase sete vezes maior por quilo de produto. As sardinhas em conserva em comparação com os outros produtos têm maiores impactes ambientais devido à energia e extracção de matérias-primas necessárias para produzir as latas de alumínio. O azeite teve uma elevada importância na avaliação global devido ao cultivo e à colheita das azeitonas. Desta forma, as acções para optimizar o desempenho ambiental das sardinhas em conserva seria substituir a embalagem e diminuir as perdas de azeite.
Devido às diferenças entre países, é necessário descrever os hábitos alimentares para dirigir mensagens aos consumidores. Através de um inquérito *online* foram verificadas correlações entre variáveis sócio-demográficas com a frequência do consumo de pescado, o conhecimento sobre pescado, e o interesse em obter informação sobre os produtos. As principais espécies consumidas são atum e bacalhau, o que está relacionado com conveniência e tradições alimentares. Os portugueses têm preferência por consumo de pescado em casa e preparado grelhado, o que revela diferenças culturais entre países. Apesar de terem um elevado conhecimento sobre pescado, um maior conhecimento não significa necessariamente escolhas mais sustentáveis. As diferenças entre os consumidores com maior e menor conhecimento sobre pescado estão relacionadas com as suas preferências de consumo. Os primeiros têm um uso mais diversificado de espécies e elevada prevalência de pequenos peixes pelágicos. Assim, um contributo para escolhas mais sustentáveis de pescado pode ser através da promoção de hábitos de consumo já existentes, que podem ser boas alternativas para o meio ambiente.
Os hábitos alimentares variam entre países e as recomendações devem ser desenvolvidas a nível nacional para que dessa forma haja maiores hipóteses de atingir os objectivos pretendidos. Os hábitos de consumo de pescado dos portugueses são em parte sustentáveis porque utilizam espécies de níveis inferiores na cadeia trófica marinha. A importância da sardinha e de outros peixes pequenos pelágicos entre os hábitos de consumo de pescado dos Portugueses são uma escolha sustentável e a ingestão de muitas espécies diferentes, além do peixe, é uma forma de evitar a pressão sobre os stocks das espécies marinhas e o risco associado à ingestão de substâncias tóxicas. A preservação de espécies de pequenos pelágicos em conservas, quando as outras formas de preservação não são possíveis, pode disponibilizar peixe para consumo humano impedindo que este seja desperdiçado ou usado ineficientemente como alimento de outros animais. No entanto, o consumo de sardinhas frescas ou congeladas representa as melhores escolhas do ponto de vista ambiental.
Contudo cada análise ambiental depende do que se compara. A produção de peixe em geral tem um melhor desempenho ambiental em comparação com a carne, mas tem restrições biológicas que limitam o seu crescimento. Para um consumo sustentável de pescado é necessário nutrir melhor com o peixe que já utilizamos, evitando desperdícios, e optar por espécies de níveis inferiores da cadeia trófica como mexilhões ou mesmo vegetais. Para além disso o pescado é apenas um ingrediente na dieta e um consumo sustentável não é alcançado se as outras alternativas resultarem em piores impactes para o ambiente.

Palavra chave: Pescado; Avaliação do Ciclo de Vida; Impactos Ambientais; Consumidores; Pesca; Sardinha; Conservas; Hábitos Alimentares.

Abstract

Seafood production from the sea is on its limit because of overfishing and environmental impacts, but consumer demand is increasing worldwide. Portugal is one of the countries with the highest seafood consumption per capita in the World. The aim of this thesis was to study the seafood consumption in Portugal to find its potential to sustainability. Four studies were developed independently, based on different methodologies including Life Cycle Assessment (LCA) and an internet-based survey. The Portuguese seafood consumption was analysed through time and it was found that it is not only driven by geography, fisheries, or resources availability. Food habits were also influenced by religion and politics. This explains that the main species is cod (salted and dried), representing around 40% of the Portuguese seafood consumption, although it does not exist in Portuguese waters. Sardine is among the species most consumed and it is the most important fish landed in Portugal. The sardine purse seine fishery is relatively efficient, both with regard to biotic and abiotic impacts, due to the schooling behaviour of the species. However stock variability and discards from slipping may be substantial. Small pelagic fish, as sardines, give large catches that can be difficult to use optimally. Canning is one way to preserve it and, canned sardines in olive oil were assessed and compared to other sardine products. The main actions to optimize the environmental performance of canned sardines would be to replace the packaging and to diminish the olive oil losses. Among different sardine products, chilled sardines performed best. Portuguese consumers have relatively high knowledge about seafood but it does not mean more interest about sustainability. Nevertheless Portuguese habits of eating small pelagic fish and different species can be sustainable choices. However seafood is only one ingredient within a diet and every environmental judgement depends on what we compare.

Keywords: Seafood; Life Cycle Assessment; Environmental Impacts; Consumers; Fisheries; Sardine; Canned; Food Habits.

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Many people that I contacted during the thesis support me to pursue, sometimes it was a simple chat. Peter Tyedmers was the first milestone, his help and motivation were essential to build up the PhD proposal. At a certain time I was up in the north, near the North Pole, with Joop Luten and Themistoklis Altintzoglou, to who I'm very thankful for the good time we spent together. Themis, it was inspiring to work with you and I hope that we had done a pleasant "song" together. Thanks for your clear thoughts! I'm very grateful to fishermen, organizations officers, and companies who kindly agreed to answer the questionnaires and provide data: PROPEIXE, APROPESCA, APARA, ANOPCERCO, A Poveira, La Gondola, and Litofish. I want to thank you all the people related to the sardine sector for helping me: Sandra Farinha, Laura Wise, Ana Marçalo, Alexandra Silva, Leonor Nunes. I would like especially to acknowledge Agostinho da Mata, for being able to explain everything about the Portuguese sardine sector in such pleased talks; Elisabete Schiek, from PROPEIXE and Cecília Leite, from A Poveira, for their endless patience in helping with sardine processing industry data; and express my gratitude to Adriano Ribeiro from Jose Gourmet, for joyful talks and enthusiasm about canned sardines and the good stuff from Portugal! Thanks to António Silva, from University of Coimbra, it was very interesting and challenging to discuss the importance of fish as cod with an anthropologist.

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Although as a PhD student most of time I had worked alone, I had always by my side other PhD students that for the best and the worst, we were together! Vanja, it was much fun to learn things with you about Portuguese fisheries and customs. Thanks for listening me about my worries so many times at the coffee, train, walking coming back home…we just missed the fishing boat together, I guess! Sara and Andreas thank you for your contribution with fruitful discussions and endless inputs, but also for being my best friends in Sweden. I had much fun with you and Sara’s little kids, bunny, frogs, together with marine biologist folks! Previously colleagues from K-team and IMM, I will always be grateful for the time we had worked together. Thanks Marta Agostinho for pushing me to the PhD “abysm”, you gave me always strength!

Family and friends in Portugal it would be difficult to refer all of you, but you are part important in most of the moments of my life. One *beijo* or *kram* to all of you and thank you for warming my life. Cientistas-de-pé, thank you for making me and people to laugh…even about the Portuguese seafood consumption! ☺ Stefan, thanks for showing me the beauty of the ocean again but also for sharing the life with me! To my father thankfulness for the moments we spent together under the sea, they still are my inspiration.

List of Publications

This thesis is based on the work contained in the following papers:

- Almeida., C., Karadzic., V., Cabral., H. and Vaz., S. 2014. Why do Portuguese eat so much seafood? – Driving forces and consequences. Submitted to *Marine Policy.*

- Almeida, C., Vaz. S., Cabral, H. and Ziegler, F. 2014. Environmental assessment of sardine (*Sardina pilchardus*) purse seine fishery in Portugal with LCA methodology including biological impact categories. *The International Journal of Life Cycle Assessment*. 19(2): 297-306.

- Almeida, C., Vaz, S. and Ziegler, F. 2014. Environmental life cycle assessment of a canned sardine product from Portugal. In press *Journal of Industrial Ecology*.

- Almeida. C., Altintzoglou T., Cabral. H. and Vaz. S. 2014. Influence of consumer's knowledge towards more sustainable seafood consumption in Portugal. Submitted to *British Food Journal.*

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List of Acronyms and Abbreviations

ASC	Aquaculture Stewardship Council
CFP	Common Fisheries Policy
COOL	Country-of-origin labelling
EPD	Environmental Product Declaration
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouse Gases
ICES	International Council for the Exploration of the Sea
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
MSC	Marine Stewardship Council
MSY	Maximum Sustainable Yield
NGO	Non-Governmental Organization
SCP	Sustainable Consumption and Production
TAC	Total Allowable Catch
TL	Trophic Level
UN	United Nations
UNCED	United Nations Conference on Environment and Development
WWF	World Wildlife Fund

Glossary of Terms [1]

Aquaculture – The farming of aquatic organisms in inland and coastal areas, involving intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators; and the individual or corporate ownership of the stock being cultivated.

By-catch - Part of a fishing catch taken incidentally in addition to the target species towards which fishing effort is directed. Some or all of it may be returned to the sea as discards.

Discards - That component of a catch thrown back after capture. Normally, most of the discards can be assumed not to survive.

Ecosystem - An organizational unit consisting of an aggregation of plants, animals (including humans) and micro-organisms, along with the non-living components of the environment.

Exclusive Economic Zone (EEZ) - A zone under national jurisdiction (up to 200-nautical miles wide) declared with the provisions of 1982 United Nations Convention of the Law of the Sea, within which the coastal State has the right to explore and exploit, and the responsibility to conserve and manage, the living and non-living resources.

Feed conversion ratio (FCR) - Ratio between the dry weight of feed fed and the weight of yield gain, it measures the efficiency of conversion of feed to fish (e.g. FCR = 2.8 means that 2.8 kg of feed is needed to produce 1 kg of fish live weight).

Landings - Weight of what is landed from a fishery at a landing site. It is different from the catch because it does not include discards.

Maximum Sustainable Yield (MSY) - The largest average catch that can be taken continuously (sustained) from a stock under average environmental conditions. It is often used as a management goal.

Overfished - A stock is considered overfished when its size falls below a minimum threshold. A rebuilding plan is required for stocks that are overfished.

[1] Based in http://www.fao.org/fi/glossary/

Overfishing - A generic term used to refer to the state of a stock subject to a level of fishing effort or fishing mortality such that a reduction of effort would lead to an increase in the total catch.

Quota - A share of the total allowable catch (TAC) allocated to an operating unit such as a country, a vessel, a company or an individual fisher (individual quota) depending on the system of allocation. Quotas may or may not be transferable, inheritable and tradable.

Stock - A group of individuals in a species occupying a well-defined spatial range independent of other stocks of the same species. Random dispersal and directed migrations due to seasonal or reproductive activity can occur. Such a group can be regarded as an entity for management or assessment purposes. The impact of fishing on a species cannot be fully determined without knowledge of the stock structure.

Target species - Those species that are primarily sought by the fishers in a particular fishery.

Total Allowable Catch (TAC) - It is the total catch allowed to be taken from a stock in a specified period (usually a year), as defined in the management plan. The TAC may be allocated to the stakeholders in the form of quotas as specific quantities or proportions.

Chapter 1.

General introduction

Prosperity consists in our ability to flourish as human beings within the ecological limits of a finite planet. The challenge for our society is to create the conditions under which this is possible.

From *Prosperity without growth: Economics for a finite planet*
Tim Jackson (2009)

1.1 Food from the sea

Fisheries are the major food production that relies on wild natural resources. However, the food production from the sea has been limited by excessive fishing pressure, growing pollution, coastal degradation, climate change and other types of pressures (Garcia and Rosenberg 2010, Rice and Garcia 2011). The global catches are restricted by the marine production (Chassot et al. 2010) but fishing is exceeding that level and as a consequence the proportion of stocks fished above biologically sustainable levels is increasing (FAO 2014). Many fish stocks are exploited at levels in excess of their maximum sustainable yield (MSY). In European Union (EU) waters 86% of the populations regulated by Total Allowable Catches (TACs) present exploitation rates higher than the MSY given (Villasante et al. 2011). Therefore, 26% of stocks are overexploited or depleted in EU (EC 2012) and overall, the number of stocks fished at unsustainable levels is 29% (FAO 2014).

With the fish stocks being depleted, opportunities to expand harvests from fisheries are limited (Rice and Garcia 2011). The depletion of local fisheries makes the fleets of the main seafood markets (EU, Japan and USA) to search for new supplies beyond their waters (Swartz et al. 2010a). Globalization and improvements in transportation, packaging, and processing; increasingly facilitate imports of seafood from all over the world (Knudson and Peterson 2007, Miller et al. 2012a). Therefore this demand exerts pressure on different parts of the oceans due to intensive practices (Villasante et al. 2012) and ambiguous fisheries protocols between countries (Corten 2014). Along with the continuously technological improvements to fish deeper and in new grounds, the marine biodiversity is being threatened with unpredictable consequences (Swartz et al. 2010b).

At the same time, research is improving the knowledge about the species biology, which is used for management purposes through for example, scientific advices that is applied as TACs by governmental organizations. Nevertheless scientists deal with natural systems, which have intrinsic uncertainty, added by low reliable data as often fisheries landings do not reflect total catches (Blanco et al. 2007, Garcia and Rosenberg 2010). Discards and by-catch are usually not included in the data sets but for some fisheries, such as demersal trawling, they represent a significant part of the catch, reaching 83% of the capture (Kelleher 2008). Moreover an ecosystem-based management could be a more realistic approach compared to the emphasis in a single target species (Heupel and Auster 2013). Nevertheless, even with scientific advices, governments apparently fail to deliver sustainable fisheries management (Mitchell 2011). The collapse of Grand Banks cod stocks in Newfoundland, in the early 1990s, was the first case whether it was recognized that scientifically based management was not effective (Agnew et al. 2014). The situation had enormous economic consequences not completely recovered yet, especially for the coastal communities, with thousands of people losing their jobs (Brunner et al. 2009).

Moreover, although the supply of seafood from fisheries has been steadily declining after reaching a peak in 1996, with 9 kg per capita, the seafood demand continues to increase (FAO 2010). The world average consumption of seafood doubled in 20 years, reaching 19 kg per capita in 2012 (FAO 2014). This increase comes mostly from aquaculture, which is growing at a rate of 7% annually and represents already 42% of the global seafood supply (FAO 2014, Tacon and Metian 2013).

Aquaculture is growing faster than any other food-producing sector (Garcia and Rosenberg 2010). Yet, several environmental challenges may limit its future growth (Péron et al. 2010). Aquaculture production discharges effluents, spreads aquatic pathogens and invasive species, and alters habitats with the related loss of ecosystem services (Jonell et al. 2013). A major constraint of aquatic farming is the reliance on wild fish for fishmeal, with subsequent protein inefficiency (Alder et al. 2008, Solér 2012). Around 30% of total catch fish landings goes for fishmeal or fish oil products that are used as feed in other human food systems (e.g. fish, poultry, pigs) (Naylor et al. 2009). It is especially the case of pelagic forage fish (e.g. anchoveta, herring, sardines) that by economic constraints from the free market access of industrial fishing companies, are used into fishmeal and fish oil competing with their use in direct human consumption (Tacon and Metian 2009). The ratio of wild fish input in farmed fish has fallen but, the consumption of fish oil in particular is determinant to the sector's demand on wild fish resources (Naylor et al. 2009). In average, it is needed 4 to 5 kg of forage fish to produce 1kg of fishmeal and the ratio for fish oil is between 20 to 25 kg of forage fish to obtain 1 kg of fish oil (Péron et al. 2010). The resources needed are more intensively to produce carnivorous fish (e.g. salmon) or species that rely on heavy energy nutrient feeds (e.g. shrimp) (Duarte et al. 2009). However, they are also used to produce herbivorous freshwater species like carp (Péron et al. 2010), because it is greatly produced in China, a country that corresponds to 62% of the aquaculture production worldwide (FAO 2014). For aquaculture to become more sustainable it needs to be less dependent on whole wild fish and to modify culture species and practices, which, in turn, will require influencing consumer preferences (FAO 2014).

Consumers are on the other side of the production and their demand is at the end of the seafood supply chain (**Fig. 1.1**). Both roles are interconnected since fishermen fish whatever the demand is and at the same time are regulated by policies. Restaurants and retailers directly respond to consumer demands but have also the potential to influence consumers about seafood from sustainable sources (Peterson and Fronc 2007). Restaurant menus for example, evidenced that when coastal resources were not available anymore, large pelagic fish were served instead (van Houtan et al. 2013). Moreover the seafood consumption trends are shifting all the time and are also dependent on many different factors, which influence the consumption behaviour in general, making the seafood consumption a complex issue which includes a combination of different research areas.

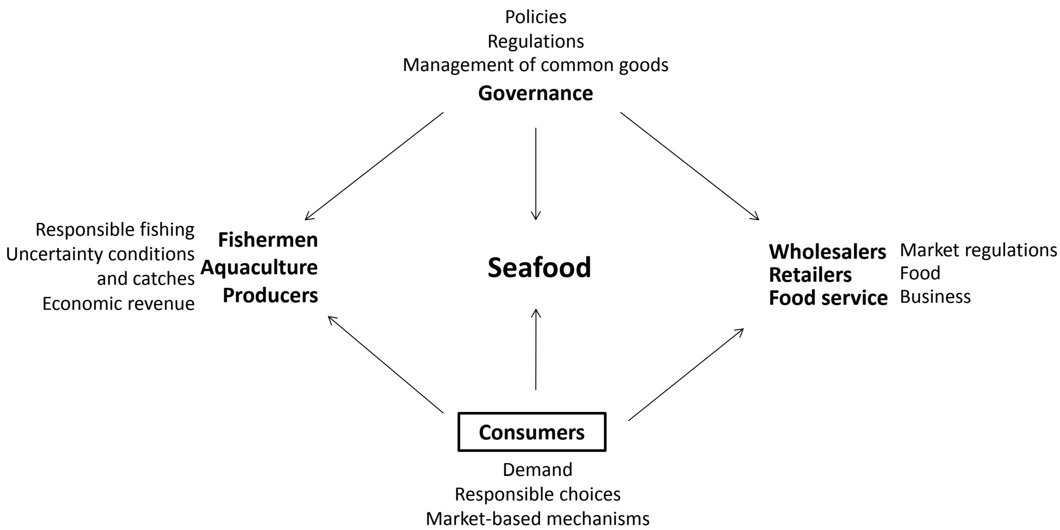

Figure 1.1 Stakeholders in the seafood supply chain.

Improvements in the seafood consumption could result in bottom-up inducement, opposing to the production that functions as top-down mechanism. However research remains to be done to understand how the consumers demand affects the supply chain and in which way it can change to more sustainable consumption. This thesis is a contribution to the knowledge on sustainable consumption and production, focusing on seafood and consumers' demand. It has an interdisciplinary approach to understand how the consumers can contribute to sustainability. The context is Portugal, which is a country with one of the highest seafood consumption per capita in the world. The thesis examines the seafood consumption habits, uses Life Cycle Assessment (LCA) methodology to assess the environmental impacts of food production, and surveys consumers to characterize their seafood choices and understand how to communicate sustainability. By seafood it includes fish, shellfish, algae, from wild and farmed production sources, and from marine or freshwater origins.

1.2 Food production and consumption: Two sides of sustainability

1.2.1 The concept of sustainability

Sustainability relates to environmental, economic and social prosperity. In 1992 at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro sustainable consumption and production (SCP) was recognized as linking environment and development (UN 1992). Two years later in Oslo, a definition of SCP was agreed as "use of services and related products, which respond to basic needs and bring a better quality of life while minimising the use of natural resources and toxic materials as well as the emissions of waste and pollutants over the life cycle of the service or product so as not to jeopardise the needs of future generations" (Norwegian Ministry of Environment 1994). In 2002, at the World Summit on Sustainable Development the world leaders signed the Johannesburg Declaration, recognizing that changing consumption and production patterns was the base for the economic and social development (UN 2002). The declaration says that “fish stocks continue to be depleted” and “the adverse effects of climate change are already evident, natural disasters are more frequent and more devastating, and developing countries are more vulnerable”.

After these statements it is globally recognized that we do need to protect ecosystems and biodiversity to feed the world (Munang et al. 2011). However, different problems need to be solved simultaneously, such as to end hunger and raise food production, while reducing agriculture’s damage to the environment (Foley et al. 2011). Even though, the motivation for sustainability is not straightforward because the individual choices are embedded in the social and institutional contexts (Jackson 2005). It is particularly challenging that consumption can be more than just essential needs, such as food; it may also be a way to achieve status and goods that position individuals on society (Shove and Pantzar 2005).

1.2.2 Environmental impacts from food production

The food system as a whole; including production, distribution and consumption; contributes between 15 to 28% of overall greenhouse gas (GHG) emissions (Garnett 2013a). In the EU, food and drinks consumption represent around 20 to 30% of the environmental impacts from household consumption (Tukker et al. 2006) and on average the impact of food per person is estimated as 7.7 kg CO_2 eq^{-1}.day (Virtanen et al. 2011). Apart from emissions, there are other important environmental impacts related to agriculture expansion and its land use, such as biodiversity loss, and the consequently destruction of habitats as deforestation (Rands et al. 2010). Of particular concern is the freshwater withdrawals devoted to irrigation (Vanham et al. 2013) and the disruption of the global nitrogen and phosphorus cycles due to fertilizers use, manure application, and leguminous crops (Foley et al. 2011).

The majority of environmental impacts from food are usually in the production phase (Garnett 2011, Virtanen et al. 2011, Infante Amate and González de Molina 2013). The intensification of food farming dramatically increased and is largely responsible for GHG emissions as such as methane, from livestock, and nitrous oxide, from fertilized soils (Foley et al. 2011). The food transportation accounts on average for only 11% of the carbon footprint of food (Nijdam et al. 2012). The amount also depends on the type of transport, since large ships have lower energy use compared to other transports, such as road transport and aircraft-freighted, which has the highest energy use per amount of food transported (Vázquez-Rowe et al. 2012). Nevertheless, larger environmental and economic gains would result from reducing food waste, increasing the food available (Garnett 2008, Foley et al. 2011). Food waste occurs at several stages within the food supply chain, from harvesting to consuming, and accounts between 10 to 40% of all food produced, including fish waste from fisheries by-catch (Parfitt et al. 2010, Pelletier et al. 2011).

Compared to other animal production, fisheries also contribute to GHG emissions but in a lower extent. They are strongly dependent on fossil fuel and as Tyedmers et al. (2005) calculated, fisheries use circa 1.2% of the global fuel use. In general capture fisheries and some extensive aquaculture present the lowest ecological foot print of animal protein production (Garcia and Rosenberg 2010, Nijdam et al. 2012). In most of the seafood products, the fishery phase is responsible for around 75% of the total energy consumption in the life cycle (Thrane et al. 2009, Ziegler et al. 2013). Nevertheless, fisheries are enormously diverse, varying from artisanal fleets to highly industrialized vessels equipped with cutting-edge technology. Furthermore the fuel use intensity is influenced by numerous factors such as fishing gear, target species, structure and vessel size, distance to the fishing ground, decisions on-board or stock abundance (Basurko et al. 2013, Ziegler and Horborn 2014).

1.2.3 Consumer choices

The consumers' dietary choices are determinant for food systems sustainability and to change them when they are not sustainable, can be extremely positive for the environment (Pelletier et al. 2011). Consumers seem to underestimate their ecological impact from food choices comparing to other environmental behaviours, such as reducing waste or saving energy (Vanhonacker et al. 2013). A multitude of studies tend to address technological potential to mitigate environmental impacts from food, but few focus on achievements in changing consumers' behaviours (Garnett 2011).

Beef and dairy products production have the greatest global warming potential impacts, between 4 to 12%, and livestock feed requires the use of large amounts of land, water, fertilizers, fossil energy, and emissions of various forms of nitrogen (Tukker et al. 2006, Westhoek et al. 2011). Therefore to change personal choices, as to reduce meat consumption, is the most important variable to decrease GHG emissions from food and land requirements, now used to grow animal feed (Leip et al. 2010, Hallström et al. 2014, Hedenus et al. 2014). Lappé already in 1971 put it like that: "there is an inefficient food policy that allows the production system to take abundant grain, which hungry people cannot afford, and shrinks it into meat, which better-off people will pay for".

Human diet has undergone significant changes in the recent decades (Infante Amate and González de Molina 2013). With globalization, the way we produce and consume food is ever more disconnected, but food emissions need to be addressed together, avoiding the displacement elsewhere in the life cycle (Garnett 2012). Modern food is highly processed, with long shelf-life, because technological innovations in food systems in the 1960s enabled to produce increasing quantity and variety of foods that are sold at lower prices (Cutler et al. 2003). Therefore with less time to prepare food at home, ready prepared food are more attractive to consumers and cooking skills, usually related with healthier food choices, tend to disappear (Cheng et al. 2007, Hartmann et al. 2013). Moreover the increase of food choices and cheaper prices in industrialised nations encourages wasteful behaviours of consumers (Parfitt et al. 2010).

The substantial contribution of meat and dairy in the Western lifestyle diets is followed by other countries wherever economic growth occurs (Speedy 2003, Gerbens-Leenes et al. 2010). The amount of meat and milk consumed in developing countries is projected to grow three times between 1997 and 2020 but still, it will be three times lower than it is in developed countries (Delgado 2003). Consumers from developed countries should take solid steps to modify their consumption, for environmental reasons but also, for an equitable and responsible use of resources

(Garnett 2013b). In this way, it is important to account for possible rebound effects, whereby GHG emissions reduction through encouraging behaviour change are not realised in practice, or even increased by compensating with other behaviours that have higher impacts (Druckman et al. 2011). Indeed, it is imperative that fish does not take the place of meat in people's diets; otherwise it increases even more the pressure on fish stocks (Garnett 2011).

1.3 Life Cycle Assessment applied to seafood

Life Cycle Assessment is a methodology that emerged as the most widely used methodology to analyse environmental impacts of food products (Pelletier et al. 2011). It gives broad and visible information regarding the origin of the products, processing, and traceability of distribution to retailers and consumers (Vázquez-Rowe et al. 2011). It is an ISO-standardized framework, that develops ''cradle-to-grave'' life cycle profiles, accounting the potential environmental impacts associated with the energy, emissions and resources consumed (Pelletier and Tyedmers 2008). A LCA study comprises four main phases: 1) goal and scope definition; which describes the product, processes included, system boundaries, and functional unit; 2) inventory analysis; to collect the data on resources use and emissions; 3) impact assessment; which aggregates the potential impacts in selected environmental categories such as climate change, acidification, or aquatic eco-toxicity; and 4) interpretation of the results; made in accordance to defined goal and scope (EC-JRC 2012). The values for each impact category are converted into indicators. For example, all GHG are grouped under the climate change impact category and then in the form of a single indicator as global warming potential (GWP), which harmonises inputs to an equivalent of kg of CO_2, often known as the carbon footprint (e.g. 1 CO_2=1 kg CO_2 eq, 1 CH_4=25 kg CO_2 eq) (EC 2010). The phases are all iterative and reviewed until the study is finished so the results become coherent with the goal and scope that defined the study. For example, a LCA study with the goal to obtain the carbon footprint for the functional unit of one kilo of sardine, needs to define the scope of the study related to boundaries of framework, processes, area of the study, and type of fishery. Then the inventory phase collects the data that constitute the inputs and outputs. The data from the impact assessment phase are aggregated and all emissions contributing to GWP are given in an amount of CO_2 kilos equivalence to produce one kilo of sardine, under the delimitations and assumptions of the study.

Seafood LCAs have shown that fishing operations are the main contributor to environmental impacts from fishery products (Avadí and Fréon 2013). The fuel use by fishing vessels typically accounts for the majority of the life cycle GHG emissions of seafood and as such, it is a relatively reliable indicator of the carbon footprint of landed, unprocessed fish (Parker et al. 2014). Other contributors to GHG emissions from fisheries, but in a smaller level, are cooling agent leakage, which can represent 13% of the total emissions (Iribarren et al. 2011). Demersal fisheries in general use more fuel and emit more refrigerants per kg of fish due to the non-schooling nature of demersal species (Ziegler and Hornborg 2014). Purse seine fisheries show the lowest fuel use intensity, especially when they are compared to trawling within the same target species, as it was seen for horse mackerel (Vázquez-Rowe et al. 2010). For Atlantic herring it was obtained five-fold lower fuel use with purse seine compared to trawling (Driscoll and Tyedmers 2010). The reverse is that, for lower fuel consumption fisheries, other operations such as ice and net production, or boat painting; may become more important to the overall assessment (Ramos et al. 2011, Vázquez-Rowe et al. 2010).

A high variability in fuel use was seen also within one fishing technique depending on the circumstances under which it is used (Ziegler et al. 2013) or target specie (Parker et al. 2014). Moreover, despite operating the same fishing gear, each vessel behaves differently depending on the skipper decision (Bazurko et al. 2013). Ramos et al. (2011) evaluated the impacts on a temporal basis for Atlantic mackerel purse seine fishery and found that pelagic species can be considerable influenced by the stock condition. However, most fishery LCA studies still fail to analyse stock assessment or other ecosystem aspects, such as discards (Vázquez-Rowe et al. 2012). It is difficult to quantify for those direct impacts and to combine LCA results with biological indicators. Nevertheless, fishery-specific impact categories have been developed, namely seafloor disturbance, discards and by-catch (Ziegler et al. 2003). Emanuelsson et al. (2014) suggested lost potential yield (LPY) as a category to quantify overfishing. If these impact categories are included in the LCA study, they can contribute to a more accurate assessment.

The results from LCA of seafood can also be used for policy purposes by considering GWP and incorporating fuel use as an additional aspect into fisheries management (Schau et al. 2009, Farmery et al. 2014, Ziegler and Hornborg 2014). More effort, and thereby fuel use, has to be spent to land fish from an overfished stock or a destructive fishing method, in terms of by-catch, discards, and seafloor impacts (Ziegler et al. 2013). Nevertheless, seafood LCAs studies give a limited picture of fisheries because they are mainly focused in European fisheries and in the Atlantic Ocean and North Sea, seldom in African waters or other oceans that are an important source of seafood worldwide (Avadí and Fréon 2013). Likewise for seafood originated from aquaculture, LCA studies do not cover homogeneously the global production. Apart from salmon (e.g. Pelletier and Tyedmers 2007, Winther et al. 2009, Ziegler et al. 2013), there are few LCAs related to other species widely consumed such as catfish (*Pangasius*) (e.g. Bosma et al. 2011), tilapia and carp (e.g. Mungkung et al. 2013), or shrimp (e.g. Cao et al. 2011). Moreover, the bulk of the aquaculture production occurs in Asia (88%), with inland and freshwater species (FAO 2014). In general, extensive aquaculture entails lower contribution to the total carbon footprint compared to intensive aquaculture, which have an opposite performance (Iribarren et al. 2010b). The amount and type of feed is what usually dominates most of the environmental impacts from aquaculture production, as it was seen for salmon (Ziegler et al. 2013), catfish (Bosma et al. 2011), and shrimp (Cao et al. 2011).

The supply chain after the fishery is ever more covered with LCA studies that analyse post-landing phases or processed seafood products (e.g. Ziegler et al. 2003, Iribarren et al. 2010a, Vázquez-Rowe et al. 2012). The LCA research can identify critical aspects or “hot spots” of production systems that contribute to the environmental impacts (Pelletier and Tyedmers 2008). A LCA study of canned tuna, up to the point of household use, had a carbon footprint largely associated with the fishing stage and the production of the tin cans (Hospido et al. 2006). Moreover the high variability found in the consumption phase demonstrated that the consumer choices influence the sustainability of the overall food consumption (Vázquez-Rowe et al. 2013). Different choices represent different environmental impacts and even within the same species, there is a large magnitude of environmental impacts depending on the source.

The communication of LCA results can be carry out for a specific good or service as an Environmental Product Declaration (EPD) or used as a “carbon footprint” (EC-JRC 2012). However, public understanding of results from LCAs and carbon footprints is still limited. Consumers are not enough informed to substitute products through carbon-based value judgements (Gadema and Oglethorpe 2011). In contrast to LCA results, consumers often consider more obvious, even if wrong, that the transportation distance is worse than the transportation mode (Kissinger 2012). Or they prefer locally grown food even though it is not always better for the environment, as some regions in the world employ more energy practices than others (Hartikainen et al. 2013). To improve the situation consumers need more information like e.g. a way to compare and make trade-offs from carbon footprints labels (Upham et al. 2011). An option could be a carbon tax for food that would increase the price of products with higher carbon footprints, and therefore make it less attractive for consumers (Tobler et al. 2011). Nevertheless, carbon footprints only relate to GHG emissions. Other environmental indicators, such as water use or biodiversity loss, are not included but are equally important when comparing different food production systems (Galli et al. 2012).

1.4 Overview about seafood consumption

1.4.1 Seafood demand worldwide

According to FAO (2014), in 2010 the total captured and farmed aquatic animal food products accounted for 17% of global population’s intake of animal protein, which can be as high as 50% for some coastal developing states. Seafood consumption has been increasing due to a growing worldwide population together with an increase in consumption per capita. The consumption of animal food products raise as people's income increases (Delgado 2003). At the same way, fish consumption across the globe is influenced by indicators of modernization, in particular economic development (York and Grossard 2004). There is an increasing demand from developing economies that cannot be met with the seafood produced that is essential to human nutrition asset or as local food security (Brunner et al. 2009, Jenkins et al. 2009). The globalization shifts seafood products away from poorer consumers to those with greater ability to pay (Garcia and Rosenberg 2010, Villasante et al. 2012). In China for example, seafood consumption is associated with luxury and social status (Fabinyi 2012). The transitional economic environment of the country have dramatically changed seafood consumption pattern, from 4.5 kg of seafood consumed per person, in 1970, to 31 kg in 2009 (Hu et al. 2014). With its large population, this consumption per capita puts an enormous pressure on the seafood supply. With limited seafood both from wild and farmed sources, it raises the need to balance the distribution of seafood resources worldwide.

Nevertheless, even if consumers are aware about the environmental impacts from seafood production, it is difficult to take responsible seafood choices by the fact that seafood products are traded from many parts of the world. Mislabelling is a threat to consumers', especially when products are commercialized already processed or prepared, as Miller and Mariani (2010) study showed that 25% of the haddock products were labelled as cod in Ireland. The seafood that is commercialized need to be under regulations to guarantee that the stocks are managed and fishing has regular control, but policies do not take action in a global perspective (Brunner et al. 2009). Therefore Illegal, Unreported and Unregulated (IUU) fish are available in markets and contribute as a source of uncertainty to fisheries management (Garcia and Rosenberg 2010). In general, consumer concerns associated to environment are related to wild vs. farmed origin of seafood, and despite mandatory indication on seafood labels in Europe, consumers are not aware of the origin of fish (Verbeke et al. 2007, Altintzoglou et al. 2011).

The increase in demand is believed by some to be met by better management, namely through an ecosystem based approach, allowing marine ecosystems to remain natural functioning systems, together with more efficient fisheries and waste reduction (Frid and Paramor 2012, Hilborn and Tellier 2012, Merino et al. 2012). At the same time, to minimize environmental impacts coming from aquaculture, it would be necessary to increase integration with food production on land, reduce animal feeds reliance on wild fish, and enhance the production of edible macroalgae and of filter-feeder organisms (e.g. mussels) (Duarte et al. 2009). Within the whole food supply, seafood has benefits when comparing fish farming to land-based animal food production since it uses less water, releases less antibiotics and fertilisers, and has lower impacts on biodiversity (Westhoek et al. 2011). Moreover, regarding to GHG emissions, farmed fish is comparable to poultry, since fish convert more efficiently feed into meat[2] (Ellingsen and Aanondsen 2006, Winther et al. 2009).

1.4.2 Consumer recommendations

Seafood is an excellent source of protein, vitamins, minerals; low in saturated fats and a primary source of omega-3 fatty acids (McManus et al. 2011). Recommendations say that aquatic food products represent highly nutritious and healthy food (Tacon and Metian 2013). In addition the regular consumption of the mixed components in seafood protects against a number of health conditions (McManus et al. 2010, Lund 2013). On the other hand, high seafood consumption also presents risks related to contamination of methylmercury (MeHg) and other toxic compounds as polychlorinated biphenyls (PCBs) (Brunner et al. 2009). High levels of MeHg are found usually in predatory species because they accumulate up in the marine food chain, with a potential risk for regular or excessive consumers of these species (e.g. tuna, swordfish, or shark) (Karimi et al. 2012, Olmedo et al. 2013) (**Fig. 1.3**). Moreover high levels of toxins such as PCBs can be found in farmed salmon because organic contaminants accumulated in fish feed, pass through the feeds to salmon (Hites et al. 2004).

[2] Fish are cold blooded organisms that do not require energy to maintain body temperature and live in a three dimensional environment, using less energy to move themselves and occupying less area.

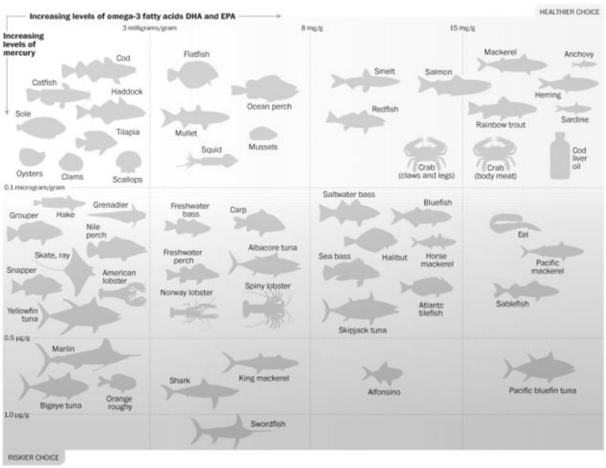

Figure 1.2 Seafood ranges from healthier to a riskier choice (Source: Joint FAO/WHO Expert Consultation on the Risks and Benefits of Fish Consumption, published by Patterson Clark at The Washington Post[3]).

Consumers need to balance health benefits against potential risks of seafood, which stresses the importance of communicating species specific advices for particular groups as children and pregnant women or in childbearing age (Ström et al. 2011, Masley et al. 2012). Consuming moderate levels of seafood would be the best way to obtain the nutritional benefits while remaining below safety limits of pollutants associated with seafood (Sirot et al. 2012). What most advices say is to eat at least two portions of fish per week, particularly fatty fish, and to diversify the species as much as possible (Kris-Etherton et al. 2002). However, the healthy benefits from intake of omega-3 fats have encouraged seafood consumption (Peterson and Fronc 2007, McManus et al. 2011). Recommendations in USA say to increase seafood intake (Oken et al. 2012) but those dietary recommendations are not sustainable if seafood needs are inherently dependent on the rest of the world, as it happens for example in Europe (Mitchell 2011). The problem is that recommendations usually consider nutritional, ecological or economic viewpoints of seafood separately and in the end the advices are fragmented and sometimes in conflict, influencing decision-making in different directions (Hicks et al. 2008, Silbernagel et al. 2011, Oken et al. 2012).

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[3] *Eat more fish; risks overstated* in www.washingtonpost.com/national/health-science/eat-more-fish-risks-overstated/2012/04/02/gIQARwPNrS_story.html**.** Published in April 3, 2012.

1.4.3 The sustainable seafood movement

The importance of informing consumers about the status of marine stocks and the limited ability from fisheries policies to change the situation, has led to a variety of organizations, including non-governmental organizations (NGOs) and aquariums, targeting consumers with advices. A sustainable seafood movement started in the 1990s with the development of different market-based mechanisms including boycotts, seafood guides, and eco-labelling programs (Roheim and Sutinen 2006) (**Fig. 1.4**). These mechanisms are designed to help consumers selecting products that match with their values and provide a market-based incentive to produce those products (Hallstein and Villas-Boas 2009, Karlsen et al. 2012). The consumer thus becomes a link via his/her power of decision to purchase and therefore it acts as a bottom-up incentive to improve the seafood supply (Erwann 2009, Pérez-Ramírez et al. 2012).

Figure 1.3 Three market-based mechanisms: a) MSC certification (www.msc.org); b) Seafood Watch program seafood guide (www.seafoodwatch.org); c) a boycott initiative from Greenpeace to a Portuguese retailer[4].

Certification is one of such instruments that assure seafood products with reduced impacts regarding to environmental standards set by an independent third party (Johnston et al. 2001). It supports producers giving opportunity to continue their activity, both from an economic and ecological perspective (Erwann 2009). Among different certification standards, there are different

[4] *Greenpeace bloqueia entrada do Pingo Doce no Cais do Sodré* in http://www.publico.pt/ciencia/noticia/greenpeace-bloqueia-entrada-do-pingo-doce-no-cais-do-sodre-1439015. Published in October 25, 2010.

goals, attributes and credibility (Karlsen et al. 2012, Miller and Bush 2014). For example, “Dolphin safe” certification for tuna has the purpose to protect dolphins however it does not consider overfishing of tuna stocks (Johnston et al. 2001, Kirby and Wod 2014).

The Marine Stewardship Council (MSC) certification established in 1997, through a cooperative effort of the World Wildlife Fund (WWF) and the multi-national corporation Unilever, is the most wide spread certification scheme for seafood. MSC has certified more than 200 fisheries, corresponding to 9% of global capture fisheries (MSC 2014). It is a scheme based on 3 principles that score the target species, ecosystem impacts, and fisheries management; requiring an annual review and full reassessment every 5 years (Agnew et al. 2014). Recently the Aquaculture Stewardship Council (ACS) started a certification programme for farmed fish, crustaceans and shellfish; with “species-specific” standards for each of 13 species groups with highest market demand (Bush et al. 2013).

The certification helps to track the supply and certified stocks are on average more likely to meet MSYs, with higher biomass and lower exploitation rates, than non-certified stocks (Gutiérrez et al. 2012). Although it does not replace regulatory measures, it can encourage the involvement of stakeholders in order to preserve the marine resources (Pérez-Ramírez et al. 2012, Jonell et al. 2013). On the other hand, the certification schemes have been criticized for lack of criteria ratifications or cases of certified fisheries from overfished stocks (Jacquet and Pauly 2007, Froese and Proelß 2012). Furthermore, the aquaculture certification has an incomplete coverage across the sector, since it has limited use in Asian markets, the main consumers of seafood products from aquaculture (Jonell et al. 2013). Moreover certification provides limited information, with just some of the many attributes that exist in seafood, and usually does not allow comparisons between products (Karlsen et al. 2012, Uchida et al. 2014b). Nonetheless a decisive factor to non-acceptance of certified products is their higher price, which is a constraint to consumers’ (Brécard et al. 2009, Hjelmar 2011).

Communication is an important element to the success of certification since it is only useful when consumers are able to recognize it. In UK for example, 70% of the public still were unfamiliar with the MSC logo (Potts et al. 2011). Moreover, Japanese consumers for example rely on the certified products only when they are aware on both the purpose of the certification and the status of the fish stocks (Uchida et al. 2014a). The consumers' reliability on certification schemes diminishes due to the many different goals that exists (e.g. eco, fair trade, social, or health purposes) (Miller et al. 2012b, Huxley-Jones et al. 2012). In addition, it is not possible that all the seafood products are certified because not all the producers' afford to be under the certification schemes. Under these circumstances buying certified products is only one possible intervention because the real challenge is to move consumption towards more sustainable patterns, so that such arrangements are the norm and not the exception (Rands et al. 2010).

Seafood guides are mechanisms that provide a ranking list in a traffic light system (red, items to avoid; yellow, good alternatives; and green, best choices). They are based on different criteria that evaluate the environmental and biological condition of species, fisheries, or aquaculture practices (Roheim 2009, Hallstein and Villas-Boas 2009). The most well-known one is the Seafood Watch program from Monterey Bay Aquarium in USA, launched in 2000, with millions of pocket guides distributed (Kemmerly and Macfarlane 2009). There are several more seafood guides in different countries as for example, those by the Marine Conservation Society (MCS), in the U.K., and Sea Choice in Canada. They are not always consistent in terms of the definition of "sustainability" and each has their own methodology, which scores species differently in accordance to the catch area, gear type, or country of origin considered (Roheim 2009).

It was shown that seafood guides maybe do not affect significantly the sales of red or green labelled seafood products (Hallstein and Villas-Boas 2013). Moreover contrary to certification, seafood guides and boycotts do not create a reward to improvements and do not discriminate irresponsible fishing individually (Roheim and Sutinen 2006). Instead, they can play other roles, as to increase awareness and empower consumers to engage in responsible choices and stimulate the collaboration between NGOs and industry in transition towards more sustainable fisheries (Kemmerly and Macfarlane 2009, de Vos and Bush 2011).

Due to the NGOs pressures, food companies and retailers also started assessing sustainable sourcing strategies, assuming commitments to sell seafood only from sustainable sources (Garnett 2011). In 1996 Unilever set a goal of 100% of its seafood would be sourced from sustainable sources until 2005, assessing internally when a fishery had not been certified by MSC (Roheim and Sutinen 2006). Retailers had followed the same type of commitment and WalMart, in USA, promised to source all its fish from MSC by 2010, a goal that it was not likely to meet (Jacquet et al. 2010). Tesco, the biggest retailer in UK, committed to have only pole and line tuna source in their own canned tuna brand, and incentivise consumers to try different fish species, but a commitment made to add carbon footprints on all their products for sale was withdrawn (Tesco 2011). Even though these types of initiatives help consumers to avoid the use of certain products, they also have been criticized by pretending to "greenwashing" corporation's image because the statements made are not always possible to achieve (Jacquet et al. 2010).

Restaurants also started to be targeted for the sustainable seafood supply chain. For example the web-based initiative Fish2Fork signs restaurants that serve sustainable seafood[5]. Moreover in 2013, McDonalds stated that it would be selling exclusively MSC certified fish in its 14000 restaurants in USA[6] and IKEA promise to use only ASC certified salmon in their restaurants by 2015[7].

Clearly NGOs play a role by accelerating the move towards the demand of seafood from sustainable sources, in both corporate and consumer decision-making (Roheim and Sutinen 2006). With so many different initiatives, they increasingly impact on defining sustainability but at the same time pressure governments' to improve fisheries management (Standal and Utne 2011). Nevertheless all these market-based mechanisms need improvements related to transparency, communication of complex issues, and cooperation between producers and organizations (Little et al. 2012). Moreover better

[5] www.fish2fork.com

[6] www.msc.org/newsroom/news/mcdonalds-usa-first-restaurant-chain-to-serve-msc-certified-sustainable-fish-nationwide. Accessed in March 2014.

[7] www.asc-aqua.org/index.cfm?act=update.detail&uid=182&lng=1. Accessed in March 2014.

understanding is needed about whether these initiatives can change consumption patterns and if more information about seafood, is related to more sustainable seafood choices.

Apart from the market-based initiatives, consumers can make relevant choices at the species level to prevent "fishing down the food chain", by choosing seafood from low levels in the marine food web, which are more abundant and rapidly replaced compared to top predators (Pauly et al. 1998). The trophic levels have different environmental costs in terms of primary production required, varying between trophic level two (e.g. mussels) and five (e.g. tuna); equivalent to eat cow meat or a hypothetic predator of cows predators (Duarte et al. 2009). Nevertheless, if substantial amounts from lower trophic levels are removed, the foraging success of a wide range of predators, as birds and marine mammals, could also be affected (Smith et al. 2011). A basic principle to sustainability is need to minimize product losses throughout the supply chain, avoiding fishing and the associated environmental costs to produce something that will be later wasted (Thrane et al. 2009, Stoner and Tyedmers *In press*).

Purchasing local products and shopping at regional markets are behaviours that can support sustainable seafood supply (Sherriff 2009, Koos 2011). Connecting producers to consumers has the potential to bring locally caught seafood and fisheries management goals to the community level (Loring et al. 2013). The information about how seafood was produced can play a major role in the supply chain transparency (Verbeke 2005). European consumers are in general interested in information regarding to freshness, geographical origin, and wild vs. farmed source (Brécard et al. 2009). The country-of-origin labelling (COOL) for example is a form of traceability, although the buyer must understand the correlation between the sourced country and the likelihood of sustainable fishing practices (Peterson and Fronc 2007). Nevertheless a large amount of information does not necessarily mean more sustainable consumption, because motivation and knowledge about seafood production are not always sufficient to shape attitudes and behaviours (Verbeke et al. 2007, Grunert et al. 2014). Potential reasons are that consumers cannot use the information as they intent or have difficulties to deal with the dynamic of the daily life and the different purchasing contexts (Leire and Thidell 2005).

1.4.4 Seafood consumption in Portugal

Portugal has one of the highest seafood consumption per capita in the World, around 62 kg per year; and it occupies the 3rd place in countries with highest seafood consumption per capita after Iceland and Japan (FAO 2010). The consumption continues to increase; between 2003 and 2008 it increased by 15% in total (INE 2010). Indisputably the most important fish in Portugal is cod (Sobral and Rodrigues 2013). The consumption of it per capita is one of the highest in the world, representing around 40% of Portuguese seafood consumption (Dias et al. 2002). Soaked cod, hake and canned tuna are the most eaten seafood products and in general, Portuguese prefer wild to cultured fish, as well as fat to lean fish (Cardoso et al. 2013b). Apart from fish, Portuguese seafood habits are remarkably diverse, with many different species groups such as cephalopods (Moreno et al. 2014), bivalves (Anacleto et al. 2014), and stalked barnacles (Stewart et al. 2013). There is a growing preference for frozen seafood, since ultra-fast freezing technology maintains high quality (Vázquez-Rowe et al. 2012), and at the same time for canned tuna since it can be prepared directly as it comes from the packaging, without bones and need of preparation before cooking.

In the past, seafood was staple food in Portugal due to subsistence consumption and habits forced by religion restrictions (Amorim 2004). As in other religious countries, this has likely contributed to shape attitudes and customs of eating fish as an alternative to meat (Miller at al. 2012a). Moreover, as regular fish consumers, Portuguese eat fish mostly because they enjoy the taste and are convinced that it is healthy (Moura et al. 2012, Brunsø et al. 2009, Pieniak et al. 2010). Frequent seafood consumers (two or more times a week), do not experience difficulties in selecting species, recognizing freshness, or preparing it at home (Hicks et al. 2008, Birch and Lowley 2012, Vasconcellos et al. 2013). Eating fish at home is common within Portuguese families and the confidence about buying and preparing fish leads to use fish regularly in meals at home (Moura et al. 2011).

Few studies had described Portuguese attitudes and preferences towards seafood and therefore there is lack of comprehensive data (Dias et al. 2002). Frequencies and species consumed by Portuguese were described by Cardoso et al. (2013b), which also found health concerns related to the high seafood consumption in Portugal; particularly hake consumption may be excessive due to MeHg intake above the probability of exceeding the provisional tolerable weekly intake (Cardoso et al. 2013a). Lately, Anacleto et al. (2014) conducted a survey study about Portuguese consumers' attitudes and perceptions towards bivalve molluscs. However, in spite of the importance of seafood in the Portuguese diet, so far, there is no study about the environmental concerns of Portuguese related to seafood consumption and to which extent their habits contribute to the overexploitation of marine resources.

In Portugal, the concept of sustainable seafood consumption was brought to public attention in 2010 with a campaign from Greenpeace that rated retailers in relation to the seafood sources in stores and released a red list of species to avoid (Greenpeace 2010). By that time a Portuguese NGO, Liga para a Protecção da Natureza (LPN), launched a website with information about the most consumed species in Portugal, and recommendations of species or fishing methods that are better alternatives for the environment[8]. A small number of initiatives were taken by private or public operators apart from the Aquarium of Lisbon campaign S.O.S. Oceans, which includes a seafood guide for Portuguese consumers[9]. More recently Docapesca, the authority responsible for fishing ports, launched events at local markets to promote fish not so popular in Portugal, such as chub mackerel[10]. Furthermore certification does not seem to have importance among Portuguese since they occupy the last place in purchase rates of certified products across European countries (Koos 2011). Certified seafood products have not penetrated in the Japanese market either, where there is also a high seafood

[8] www.quepeixecomer.lpn.pt
[9] www.oceanario.pt/
[10] www.docapesca.pt/pt/comunicacao/noticias/item/campanha-da-cavala.html

consumption together with low environmental awareness. Consumers seem unaware of the current status of the world's fish stocks, even though they are willing to pay more for such products if properly informed (Uchida et al. 2014b).

1.5 Aims and thesis outline

The overall aim of this thesis was to add knowledge to current research on sustainable consumption and production of seafood, focusing on consumer demand. One main aim of this thesis was to describe Portuguese seafood consumption qualitatively and quantitatively, and to understand drivers to find out improvements to sustainability. The other goals were to apply LCA methodology to Portuguese seafood products and to survey consumers about their interests related to sustainability. To address these broader goals, the thesis was divided into four independent chapters followed by a concluding last chapter that relates the main findings, with the following specific goals:

- To find out why Portuguese eat so much seafood, which drivers are behind it, and describe how seafood consumption patterns changed through time.
- To assess the sardine fishery, the most important fish in terms of landings in Portugal, with LCA methodology, and incorporate fishery-specific impact categories and other variables such as vessel size and time scale analysis in the LCA study.
- To assess environmental impacts of a canned sardine product using LCA and compare post-harvesting phases of a canned sardine product to other products, as frozen and chilled sardines.
- To characterize Portuguese seafood consumers regarding to frequency, habits, and type of seafood species consumed and find out if there is correlation between level of knowledge and sustainable choices.
- To analyse the outcomes from all these objectives and provide a better understanding about Portuguese seafood consumption and discuss whether sustainability can be improved.

The studies include methodologies from different research areas to combine interdisciplinary results about the seafood consumption. In that way, the thesis is structured in a paper-style format, suitable for publication, and with the exception of **Chapters 1** (General Introduction) and **6** (General Discussion), each chapter has its own Introduction, Methods, Results, Discussion and References section, and it can be read independently. As such, some repetition is likely to occur.

The thesis starts by describing seafood consumption in Portugal (**Chapter 2**). The main focus of the chapter was to describe the reasons behind such a high consumption compared to other European countries but also, the amounts and variation over time. It is expected higher seafood consumption in Portugal, as in areas with coastal access or in southern European countries, due to a greater number of seafood consumed, reflecting cultural influence on the acceptability of different species (Welch et al. 2002). However seafood consumption in Portugal is not only related to geography or resources availability, it also comes from other factors such as religion influence and politics. The consequences of such consumption habits were considered to understand whether they can be changed. Moreover recommendations to eat fish were balanced against overfishing of marine stocks and health concerns related to the intake of toxic substances from seafood (Kearney 2010, Mitchell 2011).

The most important Portuguese capture is sardine (*European pilchard*) and it is an important fish in Portuguese diet. In **Chapter 3** the sardine fishery was assessed with LCA, to find out the environmental impacts of sardine fishery and to obtain results to compare it with other foods. The aim was to assess sardine fished by the Portuguese purse seine fleet and analyse a number of variables such as vessel size and time scale within the fishery. An additional goal was to incorporate fishery-specific impact categories to complement the environmental results with biological information from the case study and find possible correlations between fuel use and stock biomass.

Sardines, as most of the fish, needs immediate processing, and small pelagic fish species have catches with large volumes of fish that are difficult to process (Blanco et al. 2007, Tacon and Metian 2009). The Portuguese canned industry traditionally conserves small pelagic fish, as sardines. In

Chapter 4 it was assessed canned sardines in olive oil with LCA methodology, a product that represents almost 50% of the canned production in Portugal (Ernest and Young 2009). The aim was to assess the environmental impacts by considering fishing, processing and packaging. The case study concerns a product of a canning factory that uses the traditional canning method and it is a first LCA study of a processed seafood product made in Portugal. Possible actions to optimize the environmental performance of canned sardines were analysed and due to consumers' difficulties to make choices between different products, the environmental cost of canned sardines was compared to other sardine products consumed in Portugal, as frozen and chilled sardines.

For LCA results to be widely used or to communicate properly about sustainable seafood choices, messages need to be adjusted to the context. Given the differences in dietary patterns among countries, there is need to understand how cultural factors influence the consumption habits (York and Grossard 2004, Warde et al. 2007). **Chapter 5** provides a survey study about the relation of socio-demographic variables with consumption frequency and how the knowledge about seafood is associated with interest in information when purchasing seafood products. Differences between higher and lower knowledgeable in seafood consumers were related to their seafood choices and discussed from a sustainability perspective.

The **Chapter 6** provides a general discussion and conclusions of this thesis. The main results from each chapter were summarized and the most important findings are discussed in terms of implications for sustainable seafood consumption in Portugal. This last chapter also revisits the initial research questions and whether they have been successfully addressed, exploring limitations and constraints of the thesis. Finally, it discusses improvements towards a more sustainable seafood production and consumption and future research needed.

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Chapter 2.

Why do Portuguese eat so much seafood? Drivers, patterns and historical perspectives

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2.1 Abstract

Portugal has the third highest seafood consumption in the world and current patterns of seafood consumption are linked by the way seafood products were embodied in the society. In this study we analysed official statistics and undertook a literature review on seafood consumption in order to explore its main drivers and consequences. Portuguese seafood consumption is characterized by a wide diversity of species and preparing modes, when compared to other countries in Europe. Cod (salted and dried) is the main species in Portuguese seafood habits. Although it does not exist in Portuguese waters, cod represents around 40% of the national seafood consumption, and several factors, as religion and tradition, promoted its consumption along time. We suggest five drivers to explain why Portuguese eat so much seafood: geography, sea resources, fisheries, social forces, and politics. Such high seafood consumption has consequences for the environment, economy and health. Hence if most dietary recommendations say to increase fish consumption, this is not applicable to Portugal. Within the scope of more sustainable seafood consumption, we discuss different future scenarios.

2.2 Introduction

Seafood are natural resources that at the same time make part of food production systems, which includes cultural and social concerns (Olson et al. 2013). They have been traded more than any other food commodity and aquatic food products represent one of the most nutritious and healthy food, with high quality animal protein low in fat (Kearney 2010, Tacon and Metian 2013). It contributes with at least 15% of average animal protein consumption and up to 50% in some coastal states (FAO 2010b, Smith et al. 2010). Moreover fish is widely reported as an important source of essential amino acids, long-chain polyunsaturated fatty acids, vitamins, minerals, and trace elements (Ström et al. 2011).

The way we feed ourselves has several environmental consequences (Scheidel and Krausmann 2011). Human diet has undergone significant changes in recent decades contributing significantly to global environmental impacts (Infante Amate and González de Molina 2011). As an example, livestock production is responsible for 10% of European greenhouse gas (GHG) emissions and several other consequences for the environment such as habitat destruction, pollution and biodiversity loss (Westhoek et al. 2011). To mitigate climate change from food, the question must be addressed not only by the way we produce it but also by the way we eat it (Garnett 2013).

To reduce meat consumption is the most important way to reduce GHG emissions coming from food and yet world meat consumption still rises every year (Kearney 2010). At the same stage, the feasibility of increasing fish consumption, as a dietary recommendation, needs to be balanced with the sustainability of marine stocks (Oken et al. 2012). The worldwide supply of seafood from capture fisheries peaked in 1986 and farmed seafood has been increasing since 1970 at an annual rate of 7% (FAO 2010b). As one can observe in recipes published over the last century, the diversity of fish species used has changed through time, and the interest increases in higher trophic levels and more vulnerable species (Apostolidis and Stergiou 2012). Moreover 63% of assessed fish stocks worldwide require rebuilding, and lower exploitation rates are needed to reverse the collapse of vulnerable species (Worm et al. 2009). But part of the marine systems' vulnerability is associated with the supply of the worlds' major seafood markets as EU, Japan and USA; which are largely dependent on seafood sources well beyond their domestic waters (Swartz et al. 2010).

To deal with this global problematic demand, which drives fishing pressure, it's critical to understand the reasons behind the consumption (Levin and Dufault 2010). To understand dietary patterns, researchers need to take into account not only ecological context and economic development, but also regional/cultural factors (York and Grossardd 2004). One needs to look simultaneously to diverse indicators which requires a huge amount of data and agreed methodologies since modern diets are shaped by many different drivers such as production, post-harvest chain, traditions, geography, demography, globalization, religion, and culture, that altogether have a significant contribution (Kearney 2010). Studying these drivers might lead to better comprehension of the food system dynamics (Dernini et al. 2013).

Viewing seafood consumption from historical, cultural and social perspectives is essential to understand how such behaviour is embedded within a vast range of values (Fabinyi 2012). We explore these issues for Portugal since it is the country with the highest seafood consumption in the European Union (EU) and one of the largest in the world (FAO 2010a). The intrinsic question then is: what do Portuguese eat? To answer this question we investigate the species and quantities that correspond to Portuguese seafood consumption. The second question is: why? To identify the reasons behind seafood importance in Portuguese food habits, we must analyse environmental, social, economic, and even the political nature of drivers. For the purpose of this paper, seafood includes all major captured and farmed edible aquatic food products entering the human food chain, including fish, crustaceans, and molluscs.

We organized the paper in three parts. First part provides the perspective of seafood supply in Portugal; we quantify flows of production, imports and exports of seafood in Portugal within the last century. Second part describes the consumption related with species and food habits in Portugal, and how the diet evolved through time. Time periods were defined with different seafood consumption patterns related to historical events since 1960. In the last part, different drivers are suggested as reasons that shaped current seafood consumption in Portugal. The paper ends by explaining consequences of such seafood consumption, which are discussed within the scope of future scenarios.

2.3 Methods

A detailed literature review was carried out concerning seafood in Portugal in order to build a narrative describing supply and consumption patterns. We gathered data from three different sources:

a) apparent consumption based on Food Balance Sheet (FBS) provided by FAOSTAT database with data from 1960 (www.http://faostat.fao.org last accessed in 2010);

b) flows of production based on national data, publications of Portuguese food balance, household budget and population surveys published by Portuguese National Institute of Statistics (INE) and;

c) literature review of past events and facts related to seafood consumption and production in Portugal.

In Portugal the fundamental information on fisheries and aquaculture production comes from INE, which releases an annual report on Fishery Statistics (*Estatísticas da Pesca*) from 1969 on (http://www.ine.pt/ last accessed in 2011). Earlier data exists, starting in 1938, but it presents a weak resolution and most species are grouped in commercial categories, with only few species-level data (e.g. sardine). Publications such as the Portuguese Food Balance (*Balança Alimentar Portuguesa*) have been published in four volumes gathering different time periods (1963 - 1975; 1980 - 1992; 1990 – 1997; 2003 - 2008) (INE 1977, 1994, 1999, 2010. For previous periods we consulted two publications with general information on Portuguese diets and problems from the start of the XX century on: Abecasis (1952) and Correia (1951).

Portuguese national health surveys were conducted during 1987, 1995/1996, 1998/1999, and 2005/2006. The sampling frame included all people living in an individual housing and information on individual food intake. For the relative seafood consumption by species we use Rodgers et al. (2008), a report about fisheries products for the European Parliament's Committee, and Cardoso et al. (2013), a research study based on internet surveys.

Data from both FBS and individual surveys are not directly comparable but nevertheless are useful to complement each other (Rodrigues et al. 2007). When interpreting consumption data, different data sources have different methodological limitations that need to be considered. There are reservations about the efficacy of statistical sources and it is difficult to correctly access values of per capita consumption by type of product (Lopes 2002). The FBS reflect national per capita supply at retail level for human consumption and represents the food produced and imported into countries minus the food exported net of imports, fed to animals, or otherwise not available for human consumption, divided by population size (FAO 2010a). The FBS show long-term trends but it does not represent the amount of food that is actually consumed because it tends to overestimate food consumption when compared with individual surveys (Kearney 2010). On the other hand individual surveys are biased by the sample, since it is difficult to cover population homogenously and people participating in the samples are influenced by different methodologies (e.g. internet surveys, face-to-face, phone).

To complement statistical data, we used descriptive information that helps understanding the reasons behind habits and important events that happened throughout times. With the information gathered, we established different time periods in terms of seafood consumption patterns. Next, based on the framework from Kearney (2010), we suggest which drivers were important to shape current seafood consumption in Portugal and what are its consequences.

2.4 Results and discussion

2.4.1 Seafood supply in Portugal

Portuguese seafood production from fisheries in recent years is around 160 thousand tonnes and 270 million Euros. Marine pelagic fish catches in Portugal are dominated by sardine, which represents more than 40% of fish catches in weight, followed by chub mackerel, tuna and horse mackerel (**Fig. 2.1**). Portuguese fishery landings are constituted by almost 40 different species categories; including fish, cephalopods, crustaceans and molluscs, comprising ca. 200 different species. The large diversity of Portuguese marine products directly influences the much diversified Portuguese seafood consumption. Apart from fish there are other seafood products, as for example molluscs, that have significant production since the 1980s (**Fig. 2.1**). Octopus is nowadays the most important Portuguese seafood product in value. Aquaculture production, represented mainly by species such as clam, gilthead seabream, sea bass and turbot, corresponds only to 5% of the seafood produced in Portugal and it has not increased in the last years.

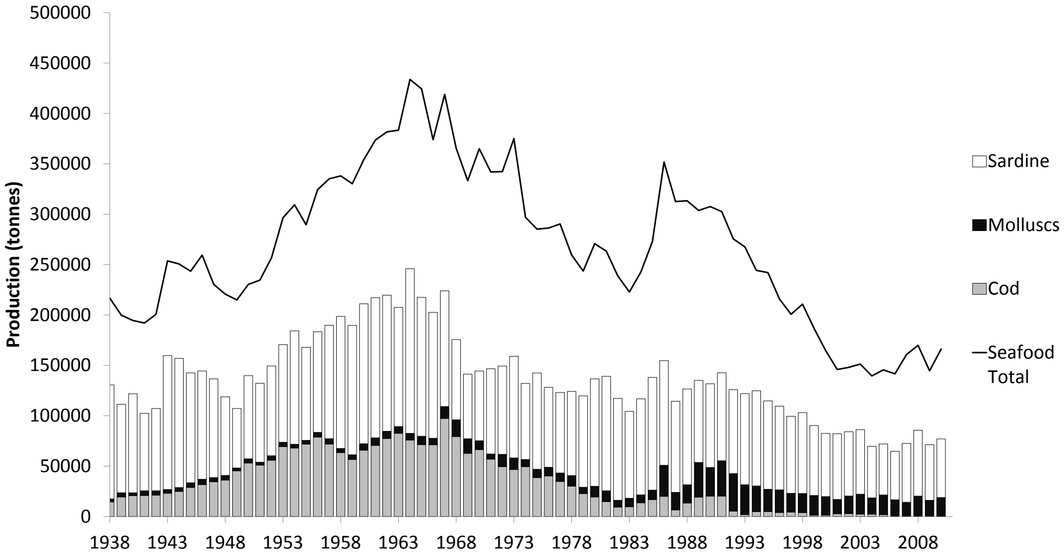


Figure 2.1 Total production of seafood in Portugal (line) and individual production variation through the years for sardine, molluscs and cod (source: Fisheries statistics, INE).

Portuguese production was never as high as in 1964 (**Fig. 2.2**) in part due to the importance of sardine landings. The second landing peak was in 1984 and from there on it has been relatively stable. Sardine has been prevalent in Portuguese fisheries for a long time. In the beginning of the XX century, the canned industry had a strong development capitalized by the sardine purse seining fishery and then trigged by the Second World War that increased canned consumption (Santos et al. 2012). After 1969, a period of low sardine production occurred and there were evidences of overfishing. At that time it was hypothesised that sardine stock had moved to northern waters of the Portuguese coast or that a “sardine cycle” existed taking circa 20 years to recover (Varão and Garcia 1975). Nevertheless the sardine stock recovered and, in 1975, the fleet made around of 200 vessels was responsible for 34% of the global landings in sardine catches (INE 1975). Sardine still continues to be the most important product in quantity. It is also the only fish that is under the Marine Stewardship Council (MSC 2013) program Certified as sustainable from 2010 on.

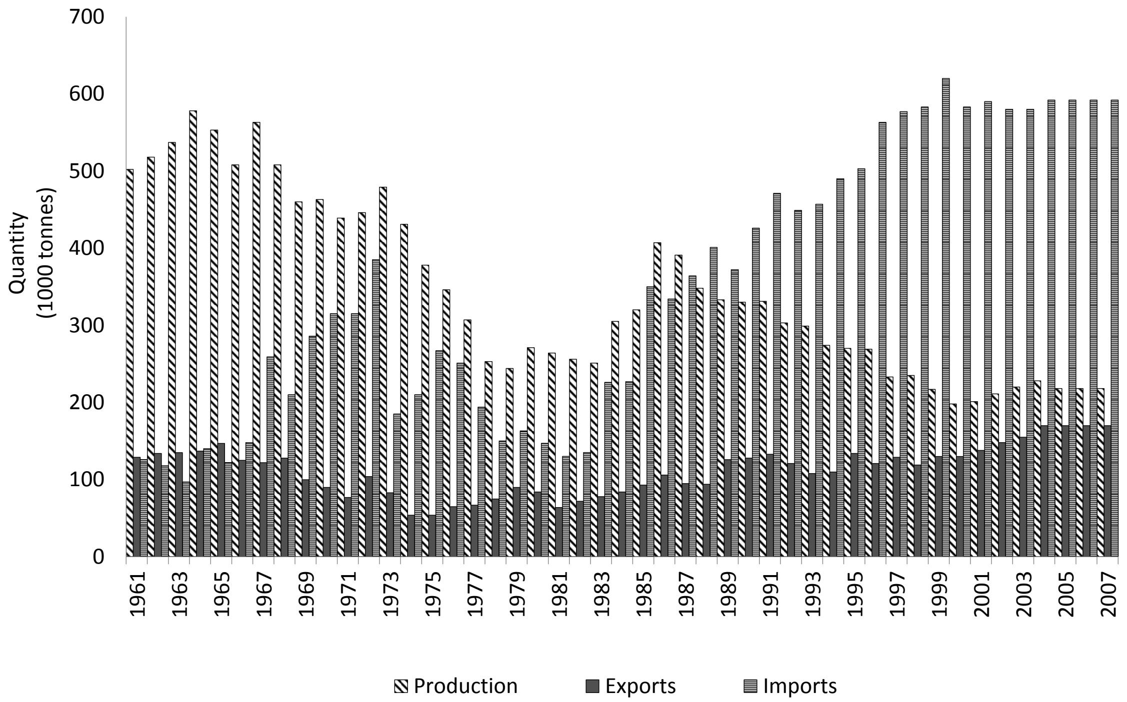


Figure 2.2 Seafood production, imports and exports in Portugal between 1961 and 2007 (source: Food Balance Sheet, FAO).

Currently, Portuguese seafood production follows a downward trend, and the national production only fulfills part of the requirements, with imports representing around two thirds of the Portuguese seafood supply and fourfold compared to exports (**Fig. 2.2**). In 2010 the negative balance was around 226 thousand tonnes and 666 million Euros, with a coverage ratio of 52%. The only positive result in the commercial balance is related to the Portuguese sector of canned products (DGPA 2007). The Atlantic cod is in fact the major imported species, representing more than 60% of the imports (Dias and Guillotreau 2005). Nowadays most of the cod processed in Portugal comes from Norway, Iceland and Russia as frozen or salty green cod (Ferreira et al. 2011). Portugal is by far the largest market for Norwegian dried salted cod; the imports reached 41 thousand tonnes and represent 60% of Norwegian exports of this product (Haagensen 2011).

Since 1967 that Portugal has been increasingly dependent of an external supply of seafood and the deficit of the Portuguese seafood commercial balance has been increasing. The Law of the Sea in the

70s and the establishment of Exclusive Economic Zones (EEZ) seriously restricted the Portuguese cod fishery (Garrido 2006). **Figure 2.1** shows how cod production declined from the 1970s on due to restrictions of fishing in international waters. Despite efforts of the fleet conversion, a predominance of smaller and less valuable codfish in Portuguese landings started (Varão and Garcia 1975). In 1986, with the adhesion of Portugal to the then European Economic Community (EEC), the fishery sector changed completely, due to the transposition of bilateral agreements (e.g. with Canada) to supra-national management by European Commission (EC) and to structural restrictions to the fleet and to catches coming from the Common Fisheries Policy (CFP) (Coelho et al. 2011).

The upward trend of seafood imports in quantity grew from 16% between 1987 and 1991, to 38% between 1990 and 1997 (INE 1994, 1999). In the 1990s, problems related to overfishing of stocks reinforced the cod production decrease. As populations declined, fishing mortality and discarding of juveniles increased to a point of commercial extinction, and in 1993 a moratorium was declared after six Canadian populations of Atlantic cod collapsed (Myers et al. 1997). However, cod food traditions and the associated processing industry remained up to now. Portugal is the only European Union member state that has an important cod salting and drying industry (Rodgers et al. 2008). Due to the low cod production and traditionally low labour costs, Portugal keeps producing salted and dried cod but with fish imported from other countries (Haagensen 2011).

2.4.2 Seafood in the Portuguese diet throughout last decades

The imbalance in seafood supply is strongly influenced by Portuguese seafood consumption patterns. Presently the national production supplies a per capita consumption of only 23 kg year^{-1}, when the current consumption is around 62 kg year^{-1} (FAO 2010a). Comparing to the world average, which rises every year, seafood consumption in Portugal is still about twice as higher (**Table 2.1**). The worldwide seafood supply grew from 11 kg in 1970 to 19 kg per capita in 2010 (Tacon and Metian 2013).

Table 2.1 Animal food source consumption in Portugal and in the world by average for 2005 (kg/capita/year) (from FAOb).

	Meat	**Seafood**	**Milk**	**Eggs**
Portugal	85.2	53.5	215.2	9.4
Europe	73.5	20.6	218.7	12.5
World	39.9	17.1	83.5	8.5

Cod is the most consumed fish representing more than half of the relative seafood consumption in Portugal (**Fig. 2.3**). After cod, the second most consumed seafood nowadays is tuna but with a consumption rate almost five times lower, 38% against 7%. Canned tuna is a staple product in Portugal, consumed by most of the people from one to four times a month (Cardoso et al. 2013). It has become increasingly convenient, according to food habits of modern lifestyles. Nowadays there is less time available for preparing food within a household and as a result there is an increase demand for pre-packed and easy food to prepare (Papageorgiou 2002). Hake is third with 6% and it can be related to the fact that frozen hake products started to become more common in the start of the XX century. In 1967 hake consumption was already higher than production (Varão and Garcia 1975). It had lower price than fresh fish, due to fisheries expansion to African countries and improvements in fishing vessels processing technology (Piquero-Zarauz and López-Losa 2005).

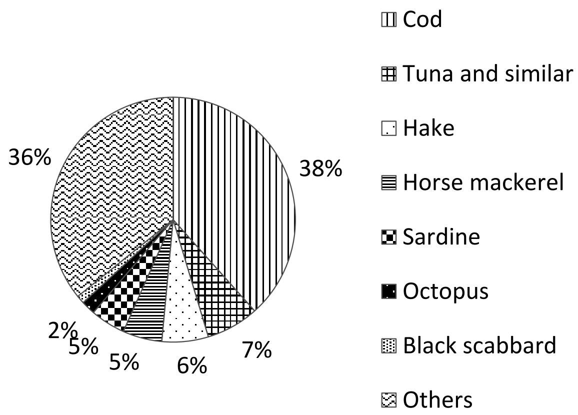


Figure 2.3 Relative house-hold consumption of the main species in Portugal assuming a per capita consumption for Portugal of 55 kg from FAO for 2005 (adapted from Rodgers et al. 2008).

Fresh seafood is predominant in Portuguese food habits, followed by salted and dried fish almost exclusively of cod (Lopes 2002). In Cardoso et al. (2013) Portuguese seafood preferences for chilled fish represent 83%, against 17% for salted/dried and 11% for frozen, smoked or canned. Fresh seafood requires a constant supply and as Rodgers et al. (2008) suggests, consumers are willing to pay high prices for good quality fish. Moreover in line with culinary conventions, fresh fish is mostly served whole, small, with bones and grilled (Cardoso et al. 2013), which is not that common in other countries. In northern Europe for example, there is an aversion of consumers towards the "whole" fish, and fillets are the common way to prepare fish (Papageorgiou 2002). The demand is satisfied by products which have undergone a considerable degree of processing and value-added (Rodgers et al. 2008). Traditional and cultural influences on the acceptability of different species for consumption can be one of the reasons for the greater number of species consumed in southern Europe (Welch et al. 2002). This might explain why Portuguese seafood consumption is remarkable diversified and several species, with less than 2% of the Portuguese seafood consumption, altogether cover 36% (**Fig. 2.3**).

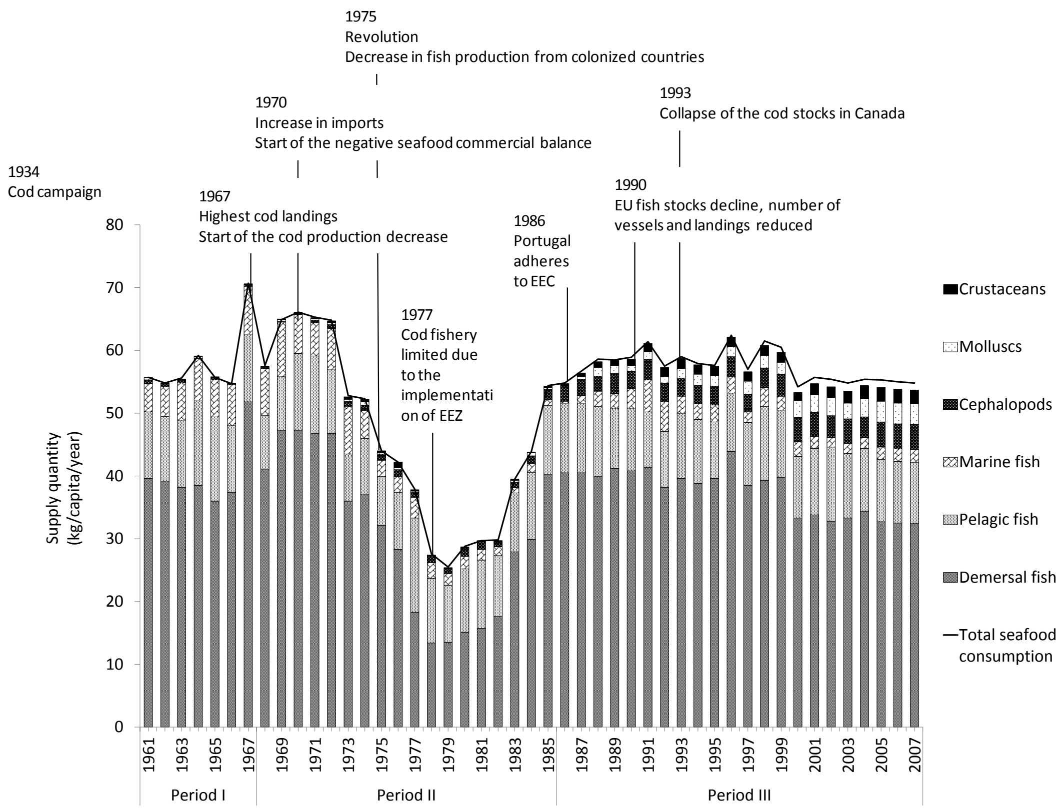
Even though it is difficult to access accurate values of cod flows since cod can be imported from different sources, in different products (e.g. frozen, salted-dried), the consumption per capita figures depend substantially on how cod is included in the statistics. As suggested by Dias et al. (2001), statistical data from the cod supply often have lags between captures and landings and it can be anomalous in some years. The difficulties to compare statistic data can result in different seafood trends. As an example, between 1992 and 1994 the Portuguese seafood consumption per capita was 37.4 kg year^{-1}. However, if converted to fresh codfish, which is the normal procedure in FAO, the Portuguese seafood consumption per capita would be 61.6 kg year^{-1} (Willemsen 2003). Which raises the question: why is that salt and dried cod is so important compared to other seafood in Portugal?

Portuguese appetite for cod fish dates back to the XV century, according to the first records of Portuguese fishing cod in the Northwest Atlantic (Dias et al. 2001). It was the Basque fishermen that disseminated the curing technique of salting fish before drying to prepare *bacalhau* (Kurlansky 1999). In the second part of the XIX century the Portuguese cod fishery increased due to taxes reduction on fish, however national production did not cover more than 10% of seafood consumption at that time (Dias et al. 2001). In 1920 the imports of salted and dried cod from Portugal were the second highest (17%) after Spain (Moutinho 1985).

In the start of the XX century the Portuguese diet was monotonic and mainly composed by *bacalhau*, the main animal protein source together with bread, vegetables, olive oil; on the other hand meat, milk or sardines were scarce (Correia 1951). In some socio-economic classes or regions there was a lack of animal protein since meat was expensive and seafood from Portuguese fishery had not a relevant supply (Campos 1977). It was difficult to raise Portuguese seafood consumption due to the lack of a network and infrastructures to maintain and commercialize fish (Varão and Garcia 1975). In the 30s and during Second World War, food production decreased in Europe and it became more expensive, reaching almost 60% of the household budget (Campos 1977). To solve part of that problem, in the 40s the importance of cod came back with the "Cod campaign" (1934 – 67), implemented by the Portuguese Government (named, for the period 1933- 1974 as *Estado Novo*) and it was based on a strong protection of Portuguese cod fishery (Garrido 2006). This cod campaign aimed at improving the cod trade balance through the reduction of imports and protection of the associated cod industries, namely the drying industry (Ferreira et al. 2011). The control of cod prices on the domestic market encouraged consumption and as a result cod intake tripled during this period and the fleet went from 51 vessels mostly with line catch, to 65 from which 32 were trawls (Dias et al. 2001).

The analysis of these trends from the 1960s on in Portuguese seafood consumption allowed us to establish three main periods (**Fig. 2.4**), each one related to specific drivers and characterized by a prominent consumption pattern. For the first period, between 1961 and 1967, we named it

"Corporate political fish" because of the influence of "Cod campaign" that raised the seafood consumption in Portugal to its maximum level. After this period, seafood consumption raised up to 1975, when it was already the highest in Europe. At that time raising consumption was no longer a priority (Varão and Garcia 1975). The period between 1968 and 1985 is characterized by a political and economic instability and so a "Fisheries crisis" forced consumption to decrease.



Time period	Corporate political fisheries	Fisheries crisis	Adaptive fisheries
Seafood consumption average (kg per capita)	58	46	57
Seafood consumption pattern	High consumption The highest ever in 1967 with 71 kg per capita	Low consumption The lowest in 1979 with 25 kg per capita	High consumption Increase of consumption of other species apart from fish

Figure 2.4 Apparent seafood consumption in Portugal between 1961 and 2007 (source: Food Balance Sheet, FAO).

Between 1990 and 1997 a new upward trend in seafood consumption was observed despite a decrease in fish, but compensated by an increase of 4% in crustaceans and molluscs, and of 15% in salted dried cod (INE 1999). During 2003 and 2008 seafood consumption continued to increase, circa 15%, but cod consumption decreased 20%, from 5.6 to 3.6 kg per capita (INE 2010). So we defined the last period from 1986 until 2009 as the “Adaptive fisheries to EU”, since there were several restrictions to fisheries but the consumption raised and it was more diversified than ever.

The data from National Health Surveys cover a decrease in fish consumption in the last years in Portugal (**Table 2.1**). Although total seafood consumption increased, it was mostly from other species rather than fish. There was also an increased consumption of other animal food products, as for example meat, which along with high seafood consumption is also very high. Compared to the worldwide supply of meat, the Portuguese seafood consumption is 85 kg per capita on average against 40 kg (**Table 2.2**) and even though seafood consumption has always being quite high in Portugal, it is not the main protein source. From total daily animal food protein intake in Portugal, around 67 g per capita, only 16 g is from seafood representing 23% (Lopes 2002).

Table 2.2 Trends in animal food products consumption in Portugal with kg per capita and the percentage of variability between periods (from National Health Surveys 1987 – 2006, INE).

	Meat	**% Change between years**	**Fish**	**% Change between years**	**Milk**	**% Change between years**
1987	71.7		55.4		65.7	
1995	79.4	10.7	54.6	-1.4	72.3	10.1
1998	80.5	1.3	53.0	-2.9	75.6	4.6
2005	80.7	0.3	49.8	-6.1	85.8	13.4

Compared to convergent diets of modern food habits, Portuguese diet was broadly based on the Mediterranean diet; with low consumption of meat, fat and processed foods (Dernini et al. 2013). But dietary patterns have changed considerably in Portugal, shifting from a traditional south European with more carbohydrate-rich staples (cereals and roots), to a more protein-rich diet with more animal products (meat and dairy) (Marques-Vidal et al. 2006). In the 1970s meat prices lowered and it became cheaper than seafood. With the 1974 revolution, the economic and social situation of the country changed profoundly. Increases in salaries brought higher economic power and consequent higher demand for more expensive food and higher life standards (Campos 1977). In the 1970s the contribution of protein in diets was mainly coming from cereals and rice (33%), and only 19% and 16% from meat and seafood respectively, but in the 1990s meat turns the highest contribution, with 29%, and seafood with 13% (INE 1994, 1999).

2.4.3 Drivers in seafood consumption

Based on the literature and on a reflexion on the Portuguese seafood consumption overview, we were able to come up with five main drivers that explain why Portuguese eat so much seafood: geography, resources, fishery, social forces, and politics. Each of these drivers has a role on how Portuguese eat seafood nowadays and all of them combined allow us to understand the importance of seafood in Portuguese habits. In order to justify why we selected them as the main drivers, a brief characterization, follows:

Geography

Portugal is a country with a long coastal area (2830 km, including its mainland, Madeira and Azores archipelagos) and a large EEZ (1.7 million km^2), amounting to almost 50% of the European Union (EU) EEZs (Leitão et al. 2014). Most of the Portuguese population lives in the coastline and Portuguese consumption of food has always been strongly based on marine resources. Higher than Portugal's seafood consumption are only Iceland and Japan, both island territories (FAO 2010a). Portuguese consumption is in the same magnitude as those nations and the geography can be comparable as a nation surrounded by sea. Other nations with a long coastline as for example Italy and Chile, have lower seafood consumption, with 25 and 23 kg per capita respectively (FAO 2010a).

Fisheries heritage

Fishing is an integral part of the Portuguese social and cultural heritage and a major means of subsistence, in particular for coastal communities that depend almost exclusively on fisheries and related activities as processing industries (Leitão et al. 2014). In 1960 the contribution of fishery to the gross domestic product of Portugal was one of the highest in Europe, only surpassed by Norway (Varão and Garcia 1975). But since the 1960s, the fleet has been reduced with a noticeable decreasing trend in catches over the last two decades (Leitão et al. 2014). Nevertheless, it is the fourth in terms of number of vessels and level of employment in the European Union (STECF 2013).

Resources

The country is in a transition zone between warm and cold ecosystems which justifies its high diversity of seafood but lower abundance. The diversity of seafood products between European countries reflects the variety of coastlines and habitats found around the European periphery (Rodgers et al. 2008). Portuguese fishery landings have almost 40 different species categories and the high productivity of small pelagic fish (e.g. sardine) is related to the sharp continental shelf and consequently coastal upwelling system (Leitão et al. 2014).

Social

The Portuguese culinary traditions are linked to habits of eating small pelagic fish, whole fish prepared with bones; and different seafood, such as octopus, cuttlefish and squids (Cardoso et al. 2013). On the other hand there were religious influences since Portugal is a Catholic country. Fish is linked with Christianity with several associations regarding fish or fishery themes in the Bible (Sobral and Rodrigues 2013). It was believed that abstaining from animal flesh in fasting days contributed to discipline and enhanced virtues, and since the Medieval era that meat was forbidden in Fridays and vigils for major feasts, as Eastern and Christmas; fish, mostly *bacalhau*, became preponderant (Coelho et al. 2011).

Nevertheless, drying and salting fish was used for product storage and the high capacity of conservation of *bacalhau* made it a vital product for long-distance trade (Ferreira et al. 2011, Oliveira et al. 2012). It was often used in the period of navigation and worldwide discoveries, in the XV and XVI centuries (Coelho et al. 2011). From there on this product has been present in the Portuguese diet but the importance in Portuguese culinary started to be constructed in the XIX century, with recipes published together with a fishery tradition (Moutinho 1985).

Cod was therefore rooted in the Portuguese culinary culture persisting up to present days, with strong influence in food habits, and it still is the main dish over Christmas Evening in most Portuguese households. The preservation process promotes important sensory changes that remain during cooking, which made cod extremely appreciated by Portuguese (Oliveira et al. 2012). This consumption seems to be strongly affected by practices since Portuguese never got used to eat fresh cod and continue faithful to *bacalhau* (Dias et al. 2001).

Politics

Food production worldwide was heavily affected by Second World War and as a result governments engaged in the implementation of food rationing systems that regulated both food supply and demand (Geyzen 2011). The political regime *Estado Novo* (1933 – 1974) promoted the cod fishery and its importance in Portuguese culinary traditions (Sobral and Rodrigues 2013). The government pretended to be less dependent on imports and to become the main intermediate with other countries and processing industries, in order to guarantee food supply at a stable price regime, and consequently fish became affordable to everyone at that time (Garrido 2006). In order to overcome the limited meat and cod supply, the *Estado Novo* government defined, in 1960, new regulations for fresh fish market establishing settings and profit margins as to raise fish consumption and fill up the lack of animal protein (Abecasis 1952).

In absolute values, if we compare the seafood consumption in Portugal with other countries, it would not be much relevant because the country has a small population. However if we use as an individual consumption case study, there are consequences of such high seafood consumption impact on the environment, economy and human health, as illustrated in **Fig. 2.5**. Consequences for the economy come from the importance of fisheries on a national and global scale. Due to the high consumption there is high importance of imports and at the same time an important industry continues to fulfil the demand, making available seafood from all over the world. Fisheries industries, as well as related suppliers such as restaurants and retailers, are key determinants of the amount, type, and form of fish that people consume by affecting the cost, availability, and desirability of different fish (Oken et al. 2012). Furthermore the popularity of healthy diets and publicity campaigns has been responsible for growing preference for fish in European countries, and fish markets are recording price rises due to the contraction in supply and increase in demand (Rodgers et al. 2008).

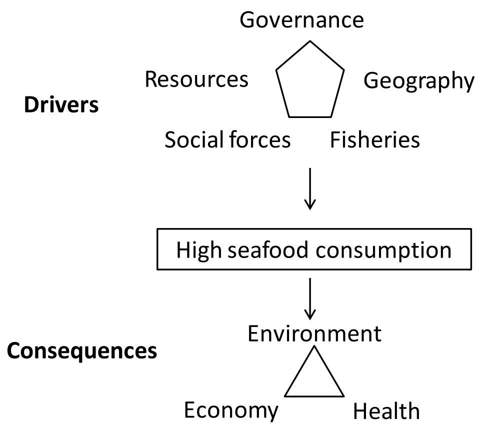


Figure 2.5 The drivers and consequences of Portuguese seafood consumption changes (adapted from Kearney 2010).

Based on the knowledge of depleted stocks status and their slow recovery process, we can claim impacts on the marine resources (Hutchings 2000). The fact that the EU seafood market is strongly dependent on seafood supplies well beyond its domestic waters (Portugal in particular), should imply a more responsible use of resources in order to avoid depleting local fish stocks in other parts of the world (Swartz et al. 2010a). On the other hand if the entire world population would eat as much seafood as Portuguese, even higher GHG emissions would come from diets (Westhoek et al. 2011). Furthermore, there are "food miles" and CO_2 emissions related to the chain that need to be accounted as environmental impacts of food commodities (Kissinger 2012).

Besides benefiting the environment and the economy, reducing seafood in Portuguese diets could also improve public health by preventing the risk of toxic substances intake. Consumers are reported as perceiving fish as healthy food but there are also undesirable consequences from over consumption of seafood. Due to the risk of mercury intake from tuna, which is a highly consumed fish in Portugal, authorities in some countries give advice of a maximum intake (Ström et al. 2011). High fish intake, in particular people who eat more than three servings of fish weekly, or more than three to four servings per month of large predatory fish, should consider lowering their intake or measuring their mercury level to determine if they are at risk (Masley et al. 2012). The European Food Safety Authority recommends that *women of childbearing age, pregnant and breastfeeding, as well as young children, select fish from a wide range of species, without giving undue preference to large predatory fish such as swordfish and tuna* (EFSA 2014). There is no national policy to Portugal, but bearing in mind that seafood consumption is higher than in most of other European countries, there is need of a public health message of balance in diet, by highlighting the risk of consuming certain fish species excessively (Olmedo et al. 2013). Furthermore it is recommended that countries should develop national lists of fish that can be eaten freely or moderately and fish that should be avoided; and these lists should consider several perspectives, with information integrating health, ecological, and economic impacts of different seafood choices (Oken et al. 2012).

Contrary to most dietary guidelines elsewhere, advice to raise seafood intake is not applicable to Portugal. Diets have enough protein and it would exert even more pressure on fisheries already stressed by over-fishing and contribute to the protein scarcity in other parts of the world. The dietary guidelines for Portuguese should integrate environmental considerations into policy development. If the consumption pattern maintains, as it has been in the last years, consumers should have guidance on the consequences of their choices and the relative environmental impacts of different species. Better connecting the consumers with producers, supporting local fishing communities, would also improve knowledge about seafood (Olson et al. 2013). Finally, a scenario based on decreasing seafood consumption would be convenient. However it is important to refer that if fish is substituted by other animal products, as meat or dairy, that would represent an even higher cost for the environment from all the three scenarios.

2.5 Conclusions

Portugal has one of the highest seafood consumption in the world and cod is the most important fish in Portuguese food habits. Portuguese culinary traditions are linked with a high diversity of resources, other organisms apart from fish (e.g. cephalopods), and the habit of eating small pelagic fish and the whole fish prepared with bones. We concluded that the high seafood consumption in Portugal is related to geography, marine living resources and the fishery heritage of the country. Politics and social forces, such as religion and habits, are also considered important in shaping seafood consumption patterns. Cod is considered a symbol of Portugal due to religion, economic, cultural and political incorporation preference for this fish along the time (Sobral and Rodrigues 2013). Seafood consumption has environmental and economic impacts related to overfishing of marine resources and highly importance of imported products. Even though fish is nutritious, an overconsumption can be unhealthy, with for example risks of high mercury intake.

The future scenarios of Portuguese seafood consumption have different challenges. Sustainable consumption is often associated with environmental consciousness but social forces and governance are also responsible for shaping individual consumption habits, as suggested here. To completely change consumption patterns rooted for many centuries in Portuguese gastronomy culture seem difficult. It might be more productive to recommend reducing seafood intake or to diversify species as a way for a more sustainable consumption. On the other hand, the Portuguese example can be used by other countries wishing to increase its seafood consumption. Nevertheless it illustrates the difficulties that consumers have when choosing a balanced and sustainable diet.

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Chapter 3.

Environmental assessment of sardine (*Sardina pilchardus*) purse seine fishery in Portugal with LCA methodology including biological impact categories

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3.1 Abstract

The purse seine fishery for sardine is the most important fishery in Portugal. The aim of the present study is to assess the environmental impacts of sardine fished by the Portuguese fleet and to analyse a number of variables such as vessel size and time scale. An additional goal was to incorporate fishery-specific impact categories in the case study. Life Cycle Assessment methodology was applied and data were collected from 9 vessels, which in average represented 10% of the landings. Vessels were divided in two length categories, above and below 12 meters, and data were obtained for the years 2005 to 2010. The study was limited to the fishing phase only. The standard impact categories included were energy use, global warming potential, eutrophication potential, acidification potential, and ozone depletion potential. The fishery-specific impact categories were overfishing, overfishedness, lost potential yield, mean trophic level and the primary production required, and were quantified as much as possible. The landings from the data set were constituted mainly by sardine (91%) and remainders were other small pelagic species (e.g. horse-mackerel). The most important input was the fuel and both vessel categories had the same fuel consumption per catch 0.11 l/kg. Average greenhouse gas emissions (carbon footprint) were 0.36 kg CO_2 eq. per kilo sardine landed. The fuel use varied between years and variability between months can be even higher.

Fishing mortality has increased and the spawning stock biomass has decreased resulting in consequential overfishing for 2010. A correlation between fuel use and stock biomass was not found and the stock condition does not seem to influence the global warming potential in this fishery. Discards were primarily of non-target small pelagic and there was also mortality of target species resulting from slipping. The seafloor impact was considered to be insignificant due to the fishing method. The assessment of the Portuguese purse seine fishery resulted in no difference regarding fuel use between large and small vessels but differences were found between years. The stock has declined and it has produced below maximum sustainable yield. By-catch and discard data were missing but may be substantial. Even being difficult to quantify, fishery impact categories complement the environmental results with biological information and precaution is need in relation

to the stock management. The sardine carbon footprint from Portuguese purse seine was lower than other commercial species.

3.2 Introduction

Sardines are a small pelagic fish that due to their small size and schooling behaviour serves as prey for other animals (Tacon and Metian 2009). *Sardina pilchardus* is an abundant species along the continental shelf of Atlantic Iberian waters, divisions VIIIc and IXa (Carrera and Porteiro 2003; ICES 2012). The spawning is driven locally and can differ depending on the environment variables that may reduce egg and larval survival (Silva et al. 2009).

Portugal is the third largest fishing nation for this species after Morocco and Algeria (Tacon and Metian 2009). Since 1980 ICES has defined an Atlanto-Iberian stock jointly managed between Spain and Portugal and around 71% is caught by Portugal (ICES 2012). Sardine is the most important species for the Portuguese fleet, around 35% in terms of volume of total landings and 14% in value (average price 0.7 EUR/kg) (INE 2011). Purse seine is one of the oldest fisheries and the most economically important fleet in Portugal (Anderson et al. 2012). Management measures for this fishery were implemented in 1998 and include an overall limitation in fishing days and annual catch limits set by the Portuguese authorities (Wise et al. 2005).

The fishery is under Marine Stewardship Council (MSC) certification since 2010 but it was suspended in 2011 due to low recruitment and high fishing mortality (ICES 2012). Management measures were implemented after an action plan decided between producers and the government with a catch limit and a fishing ban of 45 days (Fishery Management Group 2012).

The fishing fleet of Portuguese purse seiners consists of 200 vessels but the bulk of sardine catches are taken by 75 vessels that correspond to larger purse seiners (18 to 40 m size) (Stratoudakis and Marçalo 2002, Anderson et al. 2012). Almost half of the fleet (89 vessels) are below 12 m size and have low significance in terms of landing volume (roughly 9% of total landings) (Anderson et al.

2012). These smaller vessels, called *rapas* or *tucas*, are modified to capture also demersal species in relatively shallow water and can target species more valuable than sardine such as sea bream (Gonçalves et al. 2008).

In Portugal sardines are not used for feed and are mainly consumed fresh. Around 45% of the landings supply the processing industry, most of it to produce canned products (Ernest and Young et al. 2009). The domestic market is best during spring and summer, when sardine is traditionally eaten grilled, and in autumn and winter most of the landings go to processing (da Mata pers. comm.).

Food is becoming increasingly important to be produced in an environmentally sustainable and transparent way (Nijdam et al. 2012). Life Cycle Assessment (LCA) method offers a convenient means of quantifying the impacts associated with the energetic and material inputs and outputs of food products (Pelletier et al. 2007). The number of LCA studies about seafood products originating in fisheries has increased rapidly in the last years (see Parker and Tyedmers 2012; Vázquez-Rowe et al. 2012a). Previous LCA studies have shown that conventional impact categories are heavily associated with the fuel use in the fishery (e.g. Ramos et al. 2011). Three previous LCA studies of purse seine fisheries in the North Atlantic have been published (Vázquez-Rowe et al. 2010, Ramos et al. 2011, Ziegler et al. 2013) but none about the Portuguese fleet. Furthermore, most seafood LCA studies analyse data from one single year but Ramos et al. (2011) demonstrate the need to expand fishery LCAs in time. While there are many opinions on the sustainability of larger versus smaller fishing vessels, to our knowledge, no LCA studies have investigated resource efficiency in relation to vessel length.

This study is a first attempt to quantify the environmental impacts of the Portuguese purse seine fishery for sardine. We will do this by applying LCA methodology. Our goal is to quantify the overall environment impact of the fishery and to assess whether vessel length is an important factor for the fishery efficiency. Furthermore, we examine the variability of impacts over time.

3.3 Methods

3.3.1 Goal and scope definition

The main goal of this study is to assess the environmental impacts related to the Portuguese purse seine fishery targeting sardine. Additional goals are to analyse the fishery performance on a temporal basis (years; trimesters) and to compare different vessel size categories in terms of resource efficiency. The data analysed are from 2005 and 2011. The functional unit (FU) is defined as one kilo of whole sardine, landed in a Portuguese port, reflecting the function of delivering raw material for further processing to canned or frozen sardines or directly for consumption as fresh sardines. In accordance with the goals of the study, the system was limited to the fishing phase and the system studied hence comprised only production of supply materials until landing operations so this assessment constituted a so called "cradle to gate" study.

Capital goods such as vessel and gear were not included since previous findings showed that they have minor contribution to the overall environmental impacts of fisheries and seafood products (Nijdam et al. 2012. Ziegler et al. 2013). Their long life span in combination with large volumes of landings (especially in pelagic fisheries) is responsible for low influence in other studies (e.g. Svanes et al. 2011, Parker and Tyedmers 2012). The GHG emissions linked to capital goods represented less than 1% of the carbon footprint for species from commercial fishing (Iribarren et al. 2010). Also burdens related to gears do not presented relevant contributions and most cases were below 5% (Vázquez-Rowe et al. 2012a). Anti-fouling paint is mainly linked to toxicity impact categories, which were not analysed in this study (e.g. Vázquez-Rowe et al. 2012b).

For co-product allocation, we decided to use mass allocation to avoid the volatility in the market prices connected with economic allocation. Also because it can give misleading results such as that lower value species are more sustainable if caught together with high-value species than if caught separately (Vázquez-Rowe et al. 2012a). Sardine is the target species and it represents the bulk of the fishery, with almost 80% of the landings (Stratoudakis and Marçalo 2002). For more detail on

LCA methodology, see Baumann and Tillman (2004), Pelletier et al. (2007), and Vázquez-Rowe et al. (2012a).

3.3.2 Data acquisition

The samples used for this study correspond to a set of vessels belonging to different organizations based in the north of Portugal (Matosinhos, Póvoa de Varzim, Aveiro). The organizations altogether represent approximately 38% of the Portuguese sardine landings. The data obtained were from 9 vessels, in average they represent 10% of the landings for the years assessed. The vessels were divided in two size categories: larger vessels (L), above 12 metres length, and smaller (S), under 12 metres. This division was in accordance with the fleet segment published by the earliest JRC report, where we can find three main segments: 0 – 12; 12 – 24; 24 – 40 metres (Anderson et al. 2010).

The primary data for fishing vessel operations were obtained personally from questionnaires made to skippers and officers of the producer organizations (PO). Fuel use data were obtained from skippers' accountability and catches, from the PO officers' reports. In order to achieve a representative picture of the environmental performance of the analysed system and to understand how the resource efficiency varies over time, we aimed at collecting data for several years. Vessel specific data requested included the overall length, gross tonnage, propulsive engine power and an annual base of operations between 2005 and 2010. For each vessel, operational data requested included the type and amount of fuel used, coolants, ice, and lubricant oils. Annual data from landings for each vessel were obtained from the producer organization officers. For one vessel it was possible to have a monthly data series of operations and fuel per landings during the year of 2011. Differences in averages between size categories and years were tested by means of a *t* test for unequal variances. Landings data for the overall Portuguese purse seine fishery were provided by the Portuguese Institute of Statistics (INE 2011). Sardine economic values in month variability were obtained for the overall fleet from 2011 (INE 2012).

Neither discard amounts nor fishery data from a discard monitoring programme were available for this fleet. Nevertheless, a discussion based on literature data for this fishery was included since in lack of more specific data, the use of average previous estimations from published literature is recommended (Vázquez-Rowe et al. 2012a). Ice production information was obtained through personal communication with the ice production plant.

Background data (e.g. production of fuel) were compiled from the LCA database Ecoinvent 2.0 (Frischknecht et al. 2007). Emissions from fuel combustion on fishing vessels for marine diesel (e.g. CO_2, SO_x) and related to the engine (e.g. NO_x) were calculated based on Ziegler and Hansson (2003).

3.3.3 Impact assessment

The LCA was modelled in SimaPro Software Version 7.1.6 (SimaPro 2007) using impact assessment method CML baseline 2 2002 (Guinée et al. 2001). The standard impact categories included were energy use (E), global warming potential (GWP), eutrophication potential (EP), acidification potential (AP), and ozone depletion potential (ODP). The choice of these categories is consistent with the impact category choices typical for other seafood LCA research (Pelletier et al. 2007. Vázquez-Rowe et al. 2012a).

In addition, a series of fishery-specific biological impact categories were evaluated and, as far as possible, quantified. These are three LCA impact categories proposed by Emanuelsson et al. (2014): *overfishing through fishing mortality* (OF), *overfishedness of biomass* (OB), and *lost potential yield* (LPY). The OF category is based on the ratio between current fishing mortality (F) and fishing mortality at maximum sustainable yield (MSY) (F_{MSY}). It is expressed for LCA purposes as F/F_{MSY}-1 to adjust the scale so that zero corresponds to the point of "no impact" in accordance with other impact categories. OB is quantified in terms of the ratio between B_{MSY} (spawning stock biomass at MSY) and B (current spawning stock biomass) -1 and it is also set to increase with increasing environmental harm, starting at zero (B_{MSY}/B-1). Lost Potential Yield is a projection of the current exploitation scenario with regard to F and B sustained for T years forward. It represents the difference between current exploitation and more optimal exploitation with B at B_{MSY} and F at F_{MSY}. We chose 20 years as the default time perspective. For formulas and more details see Emanuelsson et al. (2014).

Two trophic indicators evaluated by Hornborg (2012) were included: the mean trophic level (MTL) and the primary production required (PPR). The MTL represents the mean trophic level in the landings of a fishery based on each species trophic level and their proportion in the total catch (Pauly et al. 1998). The trophic levels were obtained from Froese and Pauly (2012). PPR is an estimate of the magnitude of primary production needed to produce one kilo of a species at a certain trophic level (Hornborg 2012). It was calculated on landings and estimated by species groups based on 10% mean transfer efficiency between trophic levels (Pauly and Christensen 1995). We also evaluated by-catch, discards, and seafloor impact potential (SIP) proposed by Nilsson and Ziegler (2007). Due to lack of specific data for these impact categories, only qualitative data were used, based on previous studies, reports or published papers: Stratoudakis and Marçalo (2002); Wise et al. (2005); Kelleher (2008); Gonçalves et al. (2008); Gutiérrez et al. (2012); Vázquez-Rowe et al. (2012b).

3.3.4 Sensitivity analyses

Ramos et al. (2011) highlighted the fact that, in fisheries with low fuel use intensity (FUI), gear use may be an important source of GHG emissions. We do not account for this potential source of uncertainties since we do not include capital goods. Also the only information we gathered is based on a personal communication and it can be very different depending on the vessel or the fishery or even the years as we can see in Ramos et al. (2011) inventory data. To analyze the impact assessment for the gear, we made a sensitivity analysis using an average data of 0.003 kg/kg fish landed from Ramos et al. (2011).

3.4 Results

3.4.1 Inventory results

The fishing operation starts once schools of pelagic fish have been detected. On the largest purse seiners, large nets (up to 800 m long and 400 m deep) are set rapidly with the help of an auxiliary vessel (6 m long), and hauled in a largely manual operation involving all members of the crew (Stratoudakis and Marçalo 2002). Vessels operate from the ports, on daily trips (around 8 hours) and the net is set once or twice per fishing day (Wise et al. 2005). The fishery is open all year round, except during unfavorable weather conditions or during restricted periods set by producers' organization.

Main operational inputs were use of fuel, marine lubricant oil, and ice (**Fig. 3.1**). There is no use of coolants and the vessels have isothermal containers with ice and water, so called *dornas* (Wise et al. 2005). The ice is produced on land and it is sourced before each journey from ice plants based in ports. At landing, the fish is moved from the vessel into small boxes used for the auction. Lubricant oils are used for vessel engine and hydraulic machinery that helps with net operations.

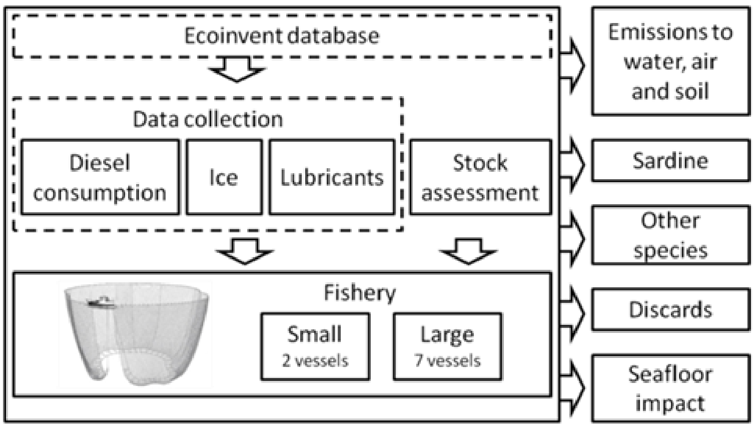

Figure 3.1 System under study for sardine (purse seine figure adapted from www.seafoodscotland.org). The sample data for diesel, ice, lubricants and stock assessment was assessed for different years, from 2005 until 2011.

Landings from overall data collected for the study were constituted mainly of sardine (90%). The remainders were other small pelagic species such as Atlantic chub mackerel (*Scomber colias*) and horse mackerel (*Trachurus trachurus*). These two species represent almost 9% of the total landings. Other species caught during purse seine fishing for sardine were documented but their catch proportion is very small and they were aggregated as other species in the data set. Discard data for purse seiners were reported as being close to zero by the interviewed skippers. They were not quantifying slipping, the discard fish directly from the net during purse seine activities mainly for quality reasons. An inventory summary regarding the main inputs and outputs of the studied is shown in **Table 3.1**. Data are aggregated for all years and per vessel length category.

Table 3.1 Inventory for fish landed in Portugal by purse seiners. Values per FU = 1 kg of sardines (standard deviation) of fish landed for the overall fleet and for different vessel size categories.

Inputs	**Unit**	**Overall**	**Large**	**Small**
Diesel	l	0.11 (0.03)	0.11 (0.03)	0.10 (0.03)
Ice	kg	0.12 (0.05)	0.13 (0.03)	0.07 (0.06)
Marine lubricant oil	l	0.005 (0.01)	0.001 (0.001)	0.019 (0.016)
Outputs				
Sardine	kg	0.90 (0.89)	0.91 (0.85)	0.77 (0.68)
Other species	kg	0.10 (0.11)	0.09 (0.15)	0.23 (0.32)
CO_2	kg	0.364	0.352	0.365
SO_2	g	0.526	0.513	0.512
NO_x	kg	0.003	0.003	0.003

The two vessel categories demonstrated highly different catch profiles and the average landing composition was different. Smaller boats catch less quantity and more species. The average proportion of sardine landed by the smaller vessels is only 77% compared with 91% for the larger vessels. The landings varied between years and the largest catches for the biggest vessels were obtained in 2008, and in 2006 for the smaller vessels.

The FUI per sardine landed was neither statistical different between years nor between vessel size categories (*t* test, p=0.35). Average values for the different years assessed varied between 0.09 (SD=0.02) and 0.14 (SD=0.03) l/kg and the fuel consumption use was highest in 2008, coinciding with the year for the largest landings of large purse seiners (**Fig. 3.2**). Both vessel categories had almost the same consumption per catch and the overall average was: 0.11 (SD=0.03) l/kg.

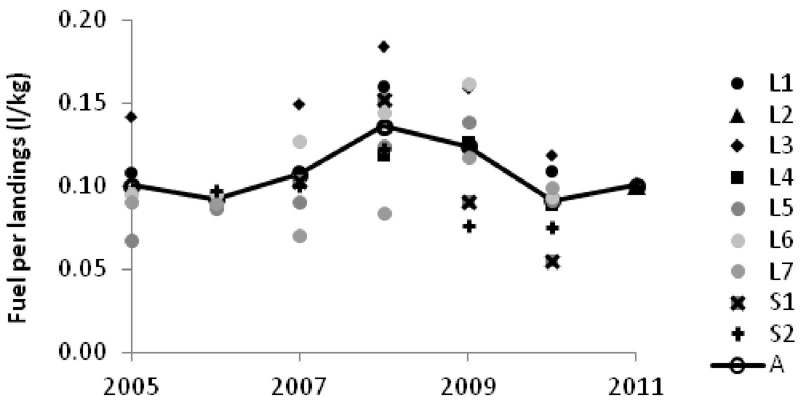

Figure 3.2 Fuel per landings of each vessel in the different years assessed (L- large; S – small and A – overall average).

The use of ice and lubricant was significantly different between vessel size categories (ice: *t* test, *p*=0.001, lubricants: *t* test, *p*=0.01). Larger vessels use more ice in their operations and smaller vessels have a higher lubricant oil use when we compare the inputs to produce 1 kg of sardine (**Table 3.1**).

3.4.2 Impact assessment

The fuel was the process with the highest contribution in all the impact categories selected for the impact assessment (**Fig. 3.3**). For the energy use it had almost 100 per cent of contribution and more than 80 per cent for the others. The relative contribution of ice production was highest for ozone depletion with 6 per cent of contribution in that category. Lubricant combustion had almost the same contribution in all the impact categories, around 4 per cent, apart from energy. Due to the dominance of fuel and the correlation between all LCA impact categories, we chose to focus on analyzing the GWP results more in detail and in relation to the biological impact categories.

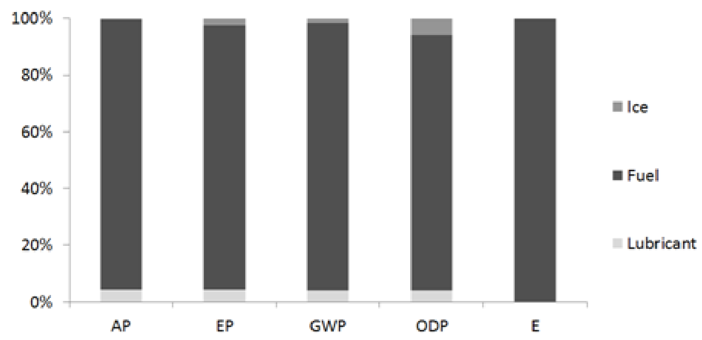

Figure 3.3 Relative results of impact assessment of the process contribution (fuel, lubricant and ice) for each impact category for the overall purse seine fishery: acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), ozone depletion potential (ODP) and energy use (E).

The average global warming potential (GWP) for the overall fleet was 0.36 kg CO_2 eq. The GWP for the two size vessel categories were almost equal: 0.35 for larger and 0.36 kg CO_2 eq for smaller boats. The same trend happens with the other impact categories due to the dominance of fuel combustion and production. For the categories eutrophication potential (EP), acidification potential (AP) and ozone depletion potential (ODP) the results for the overall fleet were 2.4E-03 kg SO_2 eq; 5.3E-04 kg PO_4 eq and 4.8E-08 kg CFC-11 eq. respectively.

The GWP varied between years from 0.29 to 0.47 kg CO_2 eq and the highest value was found for 2008 (**Fig. 3.4**). The GWP variation between months was even higher (**Fig. 3.5**). In 2011 it varied between 0.23 in the first quarter; and 0.67 kg CO_2 eq in the third quarter of the year. The months with the highest GWP were the months when sardine had the lowest economic value per weight. When we analyze the economic value of sardine during 2011, the third quarter of the year had almost half of the value comparing to first months, 1.9 and 1.0 EUR/kg respectively.

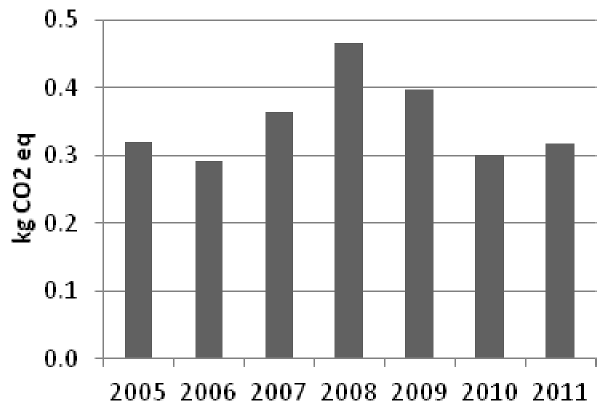

Figure 3.4 Global warming potential (GWP) average to land 1 kg of sardine for 2005 until 2011.

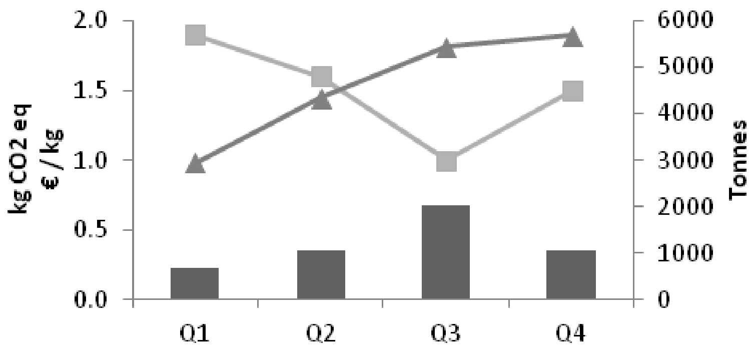

Figure 3.5 Global warming potential (GWP) average to land 1 kg of sardine for a quarter over one year on a large purse seiner (columns), average landing value (grey line) and total landings for the overall fleet (dark grey line) during the same period (INE 2012).

The sensitivity analyzes demonstrate low contribution of gear data. The highest contribution in percentage was for the EP, representing 4.5% of the impact category for the overall (**Fig. 3.6**).

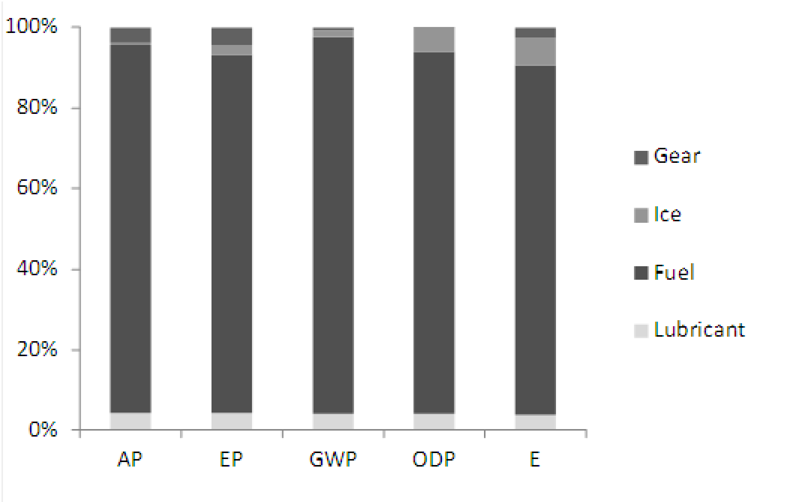

Figure 3.6 Sensitivity analyses for gear data of relative results of impact assessment for each impact category for the overall purse seine fishery: acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), ozone depletion potential (ODP) and energy use (E).

3.4.3 Fishery-specific environmental impacts

Landings from sardine Atlanto-Iberian stock are considered by ICES but no specific management objectives are given and there is no total allowable catch (TAC) set for this stock. So ICES gives advice and regarding to that, fishing mortality has increased between 2006 and 2011. The spawning stock biomass for sardine, based on the biomass of age 1 and older, decreased over the same period (**Fig. 3.7**).

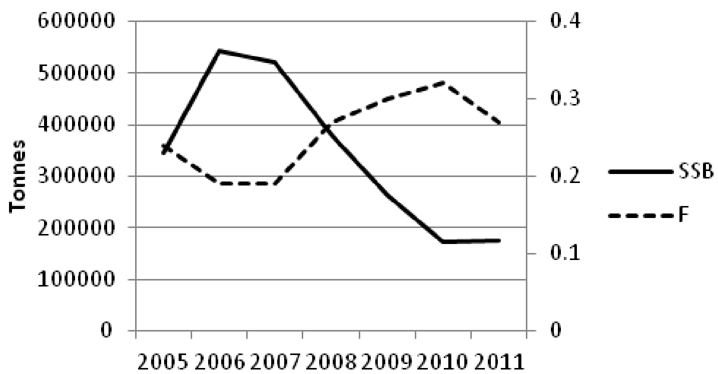

Figure 3.7 Spawning stock biomass (SSB) (Age 1 and older) (left axis) and recruitment (F) (right axis) for the assessed fishing years for the Atlantic Iberian sardine stock (from ICES 2012).

The results of the three impact categories included concerning overfishing of the target species (LPY. OF and OB). The LPY obtained was highest for 2010 (LPY=0.12 kg/kg; OF=0.78; OB=0.62). Gutiérrez et al. (2012) also concluded that the stock was in a poor condition, below the limit of reference point for 2010, and recruitment to the population could be impaired. Biomass was low and the exploitation rate was high (B/B_{MSY}=0.32 and F/F_{MSY}=1.37). The greenhouse gas emissions were highest for 2008 and no correlation between GWP and stock data was found for this stock (**Fig. 3.8**).

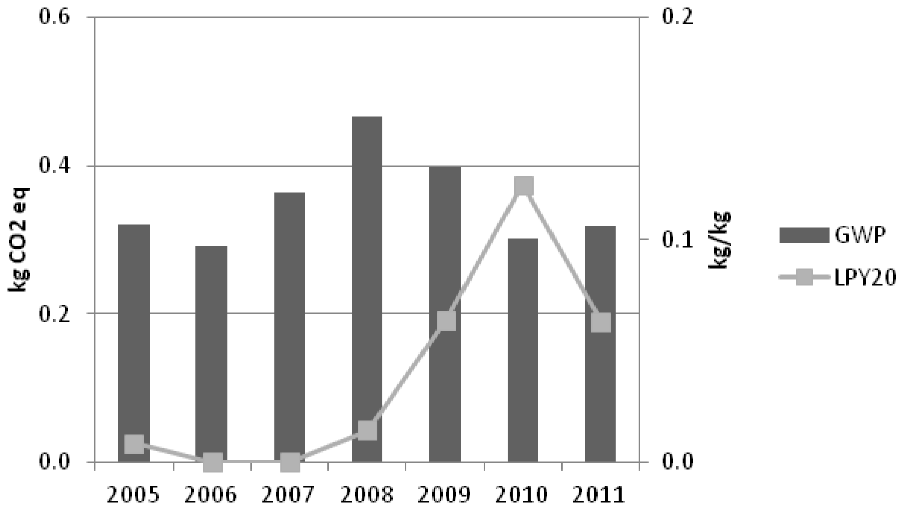

Figure 3.8 Relative results of emissions of global warming potential (GWP) and lost potential yield (LPY) calculated for 20 years time perspective.

Purse-seine fisheries can be considered to have zero discard rate because they have not been reported (Vázquez-Rowe et al. 2010). Kelleher (2008) reports an average discard rate for purse seine of 1.6% (almost negligible comparing with other fisheries), while Vázquez-Rowe et al. (2012b) reported a discard rate of 3.2%. However discard rates can be much higher if slipping is considered as discard. There is also fish mortality resulting from slipping but it is based on estimates since it relies on visual evaluation (Stratoudakis and Marçalo 2002; Vázquez-Rowe et al. 2012b). Borges et al. (2001) reported a mean discard rate for purse seiners in the south coast of Portugal from 20-30 % of the total catch. Stratoudakis and Marçalo (2002) included the slipping and estimated an even higher discard rate in sardine fishery- that some two-thirds of the total catch was slipped, leading to unaccounted mortality. Based on these literature data we assumed that per each 1 kg of sardine landed; 0.2 to 0.7 kg of fish is discarded. The discards primarily consist in non-target small pelagics with chub mackerel being the species most often slipped and discarded (Wise et al. 2005; Kelleher 2008). Catches of pelagic crab (*Polybius henslowi*) are also discarded but their survival rate is probably high (ICES 2010). Portuguese purse-seining appears not to be a threat to marine mammals however there was reported an annual by catch for this fishery of about 528 dolphins with 157 mortalities (Wise et al. 2007; Hough et al. 2010).

The seafloor impact was considered to be negligible. Purse seines are not in contact with the seafloor under normal operation and therefore does not cause any damage (Ramos et al. 2011). However, the smaller vessels have modified gears for the capture of demersal species usually with higher commercial value, such as sea breams (e.g. *Diplodus* spp.) and European sea bass (*Dicentrarchus labrax*) (Gonçalves et al. 2008). These fleets can have seafloor contact and thereby some damage, but it is not related to the sardine fishery and it was not considered as an end result.

Regarding the others fishery categories assessed, the primary production required (PPR) per landings was highest in 2005. It was due to the high proportion of horse mackerel landed in that year, which has a higher trophic level than sardine. In the three following years the PPR was lowest and ranged between 14 and 16 kg C/kg fish landed. The MTL of the landings is 3.1 and it does not vary for the years assessed (**Fig. 3.9**).

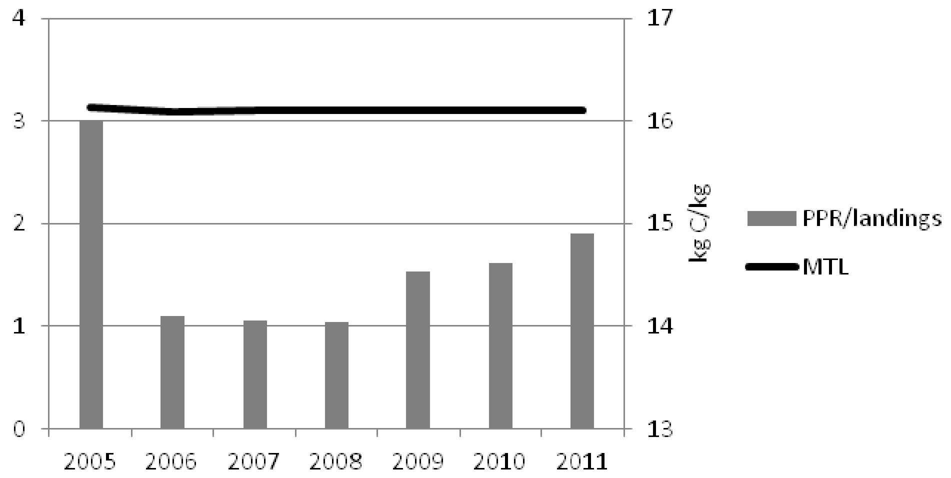

Figure 3.9 Mean trophic level (MTL) (left axis) and primary production required (PPR) (right axis) per landings for the assessed years.

3.5 Discussion

3.5.1 Environmental impact and variables

Fuel was the input with the foremost contribution to the environmental impact of sardine production. We did not find differences regarding fuel use between different size categories. The different vessel sizes were roughly equally using as an average of fuel 0.11 l/kg of sardine landed and had about the same level of environmental impacts regarding the impact categories analyzed. Smaller vessels were not more efficient in what relates to fuel consumption, even though they have a small scale production, and had somewhat higher discards and by-catch rates due to their more diverse targeting pattern.

To some extent it is possible to compare the fishery performance based on liters of fuel consumed per landings. We may conclude that the sardine Portuguese purse seine fishery has a low fuel use as Ramos et al. (2011) has shown for purse seine fishery in Basque Country (average value of 0.03 l/kg). It is especially low when compared with other high-value commercial fisheries. Those are usually of larger and higher trophic level species, as for example cod, which can have a fuel use between 0.29 l/kg (Svanes et al 2011) and 1.0 l/kg (Ziegler et al. 2003). The result obtained here is in the same range as other purse seine fisheries of small pelagic stocks. For example the South American pilchard has a fuel use of 0.11 l/kg (Parker and Tyedmers 2012) and the Atlantic herring of 0.14 l/kg (Ziegler et al. 2013).

When the results are compared with Joint Research Council (JRC) data for the Portuguese purse seining fishing fleet, the overall fuel use was around the same. In this study we obtained for the overall fleet, in 2008, 2009 and 2010, a fuel use of 0.14; 0.12; and 0.09 l/kg, and in JRC data of 0.11; 0.12; and 0.13 l/kg for the same years assessed (Anderson et al. 2010, 2011, 2012) (**Table 3.2** and **Table I** in **Appendices**). Although there are differences in the fishery between ports and Portuguese regions (Stratoudakis and Marçalo 2002) we may conclude that the data collected seem to be representative of the Portuguese purse seining fleet. Our result that the fuel use does not vary with vessel size categories is also consistent with JRC data: smaller vessels are not more (and not less) energy efficient than larger ones. While we use the JRC data on energy use to verify our own results, one could also see this study as verification of the JRC data collection and up scaling methodology from a sample of vessels to cover a whole fleet. It also demonstrates that JRC data could be useful to use in analyses of this and similar fisheries, when there is not sufficient time to collect specific data. When we analyze other types of information, as employment or economic yield in the JRC data set, there are differences between small and large vessels: large vessels employed fewer fishermen and have lower revenue per landings. In contrast to other findings (e.g. Jacquet and Pauly 2008), in this fleet small-scale does not seem to be more sustainable from the environmental point of view than large-scale. Passive fishing methods (gillnet, lining and creel) have been shown to be more resource-efficient than active fishing methods like trawling (e.g. Ziegler and Hansson 2003**,** Iribarren et al. 2010). Boats fishing with passive gears are often smaller than those fishing with active gears and the widespread view that small-scale fisheries are more sustainable probably stems from this fact. Purse seines are considered as semi-active gear type and are difficult to fit in on this scale.

Table 3.2 Data from JRC for purse seine fishery in Portugal. Data for different years aggregated by size: small (0–12 m), large (12–40 m), and overall (0–40 m) (Anderson and Guillen 2010; Anderson et al. 2011, 2012).

Size	**2008**	**2009**	**2010**
Fuel per landings (l/kg)			
Small	0.09	0.13	0.15
Large	0.11	0.12	0.13
Overall	0.11	0.12	0.13
Labour per landings (crew / tonne)			
Size	2008	2009	2010
Small	0.13	0.11	0.09
Large	0.02	0.02	0.02
Overall	0.03	0.03	0.03
Value per landings (EUR / tonne)			
Size	2008	2009	2010
Small	1.20	1.07	0.92
Large	0.63	0.70	0.14
Overall	0.66	0.74	0.60

The fuel use varies between years and the highest value was found for 2008. In the same year, landings were also highest and the result might be related with the fact that in order to catch more fish (due to market demand) vessels were less efficient in their operations. Despite not being significant because we only had data for one vessel from one year, the variation within a year was larger than between years. The months with the highest fuel use were the months with lowest sardine market value and the highest landings. In these spring and summer months, it is a cultural habit to eat grilled sardines in Portugal, being the traditional dish in festivities. The rise on the demand decreases the value per weight as a consequence of the increased production and effort, resulting in a less efficient fishery. Even though these results should be interpreted with caution, they reinforce the need for a timeline analysis in different stocks and the timeframe expansion, perhaps even on a finer scale than years (Vázquez-Rowe et al. 2012a). Fisheries with different characteristics may vary on other time scales (e.g. Ramos et al. 2011), even between months and seasons, as we have seen in this study.

3.5.2 Fishery-specific impact categories for sardine

In recent years, the stock has decreased as a result of increased fishing mortality and low recruitment. Ecosystem driven reasons, and some uncertainty regarding to the extent of sardine movement and surveys for the stock management, can justify the condition (ICES 2012). The biomass and exploitation rate relative to MSY reference points were higher than targeted values (Gutiérrez et al. 2012). The LPY, that reflects the difference between the long-term yield at current stock status and at more optimal levels, was highest for 2010. For each kilo of sardine landed in 2010, 0.12 kg of potential yield was lost due to over-exploitation. Nevertheless it is a low LPY and when ranked with other stocks assessed by ICES, the sardine stock ranks as a median value compared with stocks of other species, as for example cod (Emanuelsson et al. 2014). Values for 2011 demonstrate a slight recovery of the stock. More recently, the suspension of the MSC certification in 2012, and the consequent management program during that year, seemed to allow the stock to recovery. Values of FO for 2012 were inferior to FO in 2010 (0.61 and 0.78 respectively), and in 2013 the certification was lifted (MSC 2013). It seems that a management plan can protect the stock in periods of poor recruitment, allowing a sustainable yield and also to avoid unnecessary fluctuation in the catches (ICES 2012).

The stock assessment data showed a poor relationship with GWP. We have not found evidence that the environmental performance of this pelagic species fishery is influenced by the availability of fish in a given time of period as did Ramos et al. (2011). Also Emanuelsson et al. (2014) demonstrated for other pelagic species, that the stock-fuel relationship, that has been suggested especially for demersal species (e.g. Thrane 2006, Ziegler 2003), is not a reliable two-way mechanism. Improved status will lead to a better environmental performance, also equal, but better environmental performance does not necessarily indicate a better stock status. Due to the schooling nature of pelagic species, the “stock effect” is expected to be less pronounced as more time is spent searching for the fish when fishing for pelagic species or in other words fishing effort-fuel use and catches are more closely correlated in demersal fisheries. Many other factors in addition to fish abundance contribute to the environmental performance of the fishery, perhaps most importantly by fisheries management, through quota setting and distribution, but also the economic value of the fish. With a higher value, it can be worth staying out a little longer or go out more often, as was indicated by the monthly data in this study.

The Portuguese purse seine fishery had a low MTL of 3.1 and it does not vary through time as in Basque purse seine with a MTL range between 3.0 and 3.6 (Ramos et al. 2011). It only reflects the fleets perform but it means less marine food web depletion and lower impact of the fishery on the ecosystem (Pauly et al. 1998). However, findings had alerted that fisheries are also depleting species from low trophic levels (Pinsky et al. 2011). A temporary collapse of the sardine stock could have impacts by reducing food supply for other marine animals and exert bottom-up control for predators or top-down control on prey species (ICES 2012). Even though sardine is more sustainable when compared with other species from the marine food web, careful should be taken in case of very high exploitation yields.

Other fishery impact categories such as by-catch and discards were described and had a high rate, especially when compared to other pelagic fisheries. Highly variable and sporadic discarding behaviors exist if slipping is considered as a discard practise (Wise et al. 2005) and based on published data we assumed that per kilo of sardine landed, 0.2 to 0.7 kg of fish were discarded. Since these data are sparse and very variable, a monitoring program for discards in this fishery would be useful to resolve the uncertainty. Even being difficult to quantify, the fishery-specific impact categories add valuable information for certification schemes and to a complete environmental assessment of the fishery (Emanuelsson et al. 2014). If we had only included traditional LCA impact categories the fishery would have a very good environmental assessment, but the inclusion of stock information and biological impacts shows that there are problems and they need precaution to the sustainability of the stock.

3.5.3 Carbon footprint of sardine

The *Sardina pilchardus* carbon footprint from Portuguese purse seiners (0.36 kg CO_2 eq./kg) was almost half when compared with other purse seine fisheries, as for example purse seine fishery in Galicia (0.78 kg CO_2 eq./kg) (Iribarren et al. 2011) or horse mackerel purse seine (0.80 kg CO_2 eq./kg) (Vázquez-Rowe et al. 2010). Only purse seine fishery in Basque Country has even lower carbon foot print (between 0.04 and 0.09 kg CO_2 eq./kg) (Ramos et al. 2011). Those fisheries included more inputs in the inventory such as cooling agents, not used in purse seine in Portugal, which represented 5% of the total GWP (Vázquez-Rowe et al. 2010). They also included net production, an important contributor in Ramos et al. (2011) that represents 9% of the GWP in Vázquez-Rowe et al. (2010), excluded from this study since it was considered a capital good with a long life span.

Anyway, if we had done the same assumption as Tyedmers et al. (2007), that energy inputs to provide boats and gear would amount to 10% of the direct fuel energy, the purse seine would still have been very efficient compared to the other fisheries. Their study, about the European pilchard fishery in UK that operates with a similar gear and set the fish aboard into large tanks of refrigerated seawater (RSW tanks) and ice, gave a similar carbon footprint (0.25 kg CO_2 eq./kg) (Tyedmers et al. 2007). From these comparisons we may realize that even the same fishing gear can have highly heterogeneous energy use and related emissions of fisheries.

Small pelagic fish species as sardine represent the largest catches and are the major group of species fished for non-food use globally (Tacon and Metian 2009). Given the relatively low environmental impact of this fishery increasing the amount of fish used for direct consumption should be a top priority (Jacquet et al. 2010). As other purse seine fisheries (Ramos et al. 2011), when compared to fisheries for other species (Ziegler et al. 2013), and even land –based animal production (Nijdam et al. 2012), sardine fishery came out as one of the most energy efficient types of animal protein available. If fisheries management takes into account stock information to sustainably exploited levels, Portuguese sardine will not only provide a healthy and highly valued cultural meal, but also a sustainable source of food.

3.6 Conclusions

Large differences in environmental performance in the purse seine fishery were found between years, with indications that variability could be even larger between months within a year. The LCA results were driven by fuel production and combustion and all typical LCA impact categories closely followed GWP. We have found no difference in fuel use between large and small vessels and stock condition and energy efficiency were not directly correlated. Biological impact categories are an important complement to LCA to provide a more complete picture of the environmental impact of a fishery, without them some results of this study had been misleading. The carbon footprint of sardines landed in the studied purse seine fishery is low when compared to other fisheries and a long-term management plan is needed for the fishing sustainability.

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Chapter 4.

Environmental life cycle assessment of canned sardines from Portugal

In press in *Journal of Industrial Ecology*

Almeida, C., Vaz, S. and Ziegler, F. 2014. Environmental life cycle assessment of a canned sardine product from Portugal.

4.1 Abstract

This study aims to assess the environmental impacts of canned sardines in olive oil, by considering fishing, processing and packaging, using life cycle assessment methodology. The case study concerns a product of a canning factory based in Portugal and packed in aluminum cans. It is a first LCA of a processed seafood product made with the traditional canning method. The production of both cans and olive oil are the most important process in the considered impact categories. The production of olives contributes to the high environmental load of olive oil, related to cultivation and harvesting phases. The production of aluminum cans is the most significant process for all impact categories except ODP and EP, due to the high energy demand and the extraction of raw materials. To compare to other sardine products consumed in Portugal, such as frozen and fresh sardine, transport to the wholesaler and store was added. The environmental cost of canned sardines is almost seven times higher per kilogram of edible product. The main action to optimize the environmental performance of canned sardines is therefore to replace the primary packaging and diminish the olive oil losses as much as possible. Greenhouse gas emissions are reduced by half when plastic packaging is considered rather than aluminum. Nevertheless canned sardines represent a fish product without need for refrigeration during transport or storage. Furthermore it makes it possible to use the fish for human consumption when other sardine products are not possible; preventing that it is wasted or used sub-optimally as feed.

4.2 Introduction

European pilchard (*Sardina pilchardus*) is the most important fish in terms of quantity landed in Portugal (INE 2012). It is caught by purse seines in Portuguese waters by a fleet of around 200 vessels, between 18 to 40 m long (Stratoudakis and Marçalo 2002). The Atlantic-Iberian stock is jointly managed by Spain and Portugal (ICES 2013). Vessels operate on daily trips and have isothermal containers with ice and water (Wise et al. 2005). Fishing operations start with detecting the schools of fish to then set and haul the net (Stratoudakis and Marçalo 2002). Main operational inputs from Almeida et al. study (2013) are fuel, marine lubricant oil, and ice. Almost half of the sardine landed is consumed fresh by Portuguese, around 40% goes to factories, of which the main part (78%) goes to the canning industry, and it is not used for feed (Ernest and Young 2009).

Canning is one of the most common ways to preserve seafood that maintains the nutritional value and food safety without additives or preservatives (Lyon and Kiney 2013). Canned seafood products are eaten all over the world, and are important for human nutrition since they can be stored for a long time, are ready to consume, and affordable for most people (Vázquez-Rowe et al. 2012b). The most commonly canned species include tuna, sardines, and molluscs (FAO 2011). The demand for canned tuna has increased since the 1960s and it is now the most commonly consumed fish in the United States (Miyake et al. 2010). Because tuna has high levels of mercury, several national authorities, including the US Food Drug Administration (FDA), give recommendations to avoid risks of mercury intake from canned tuna consumption (Burger and Gochfeld 2004).

In Portugal there are 20 fish canning plants producing around 44 thousand tonnes of canned products annually (INE 2012). It is a sector made mostly of small firms, with mainly women employees, but the product quality is appreciated in international markets, with around 65% of the production exported (COTEC 2012). Portuguese production of canned sardines represents 8% (74 133 tonnes) in the world and is the third highest after the two largest producers Morocco and Algeria (Ernest and Young 2009). The cans are made by two pieces and have rectangular shapes to benefit the fish presentation (Poças 2003). Canned sardines represent almost 50% of the total canned production in Portugal and can be marketed in different products such as sardines in vegetable oils, tomato sauce, or olive oil, which is the most important in terms of volume and value (Ernest and Young 2009).

Processing starts with storage of sardines that are often landed in high quantities and need to be stored chilled or frozen (Aubourg 2001). The cooking step, to reduce moisture and inactivate endogenous enzyme activity, can be done in two different ways: the raw pack method, where sardines are cooked in the can (modern method); or alternatively the sardines can be cooked before being packed into cans (traditional method) (Warne 1988). The sterilization at very high temperature afterwards destroys pathogenic contaminants and other microorganisms capable of growing at storage temperatures (Myrseth 1985). The difference between these methods is in the cooking phase, where the modern method is faster and decreases production costs. Nowadays only a few plants in Portugal stick to the traditional method.

The responsible use of raw materials, prevention of waste, and efficient use of energy and packaging within the product chain represents both economic and environmental savings (Bugallo et al. 2012). Life Cycle Assessment (LCA) is a method used to quantify the impacts of products associated with inputs of energy, materials and other resources together with the outputs (Baumann and Tillman 2004). It provides information about the environmental performance of the entire product chain, including processing, consumption and end of life of products (Iribarren et al. 2010b). There has been a rapid increase in fisheries LCAs but comprehensive assessments of supply chains are also needed (Avadí and Fréon 2013). There is a high variety of seafood products for human consumption but still few LCA studies of highly processed seafood products, more than fillets or frozen products (Vázquez-Rowe et al. 2012a). As for example the production of frozen cod fillets (Ziegler et al. 2003), the chain of value of cod products from fishing to retail (Svanes et al. 2011), or frozen octopus (Vázquez-Rowe et al. 2012a). Two LCA studies of canned seafood products were published, one of tuna (Hospido et al. 2006) and one of mussels (Iribarren et al. 2010a, 2010b), both from Galicia, north of Spain. More recently, a publication of European pilchard was published, comparing sardine products using LCA methodology (canned sardines, fresh sardines and European hake using sardine as bait) (Vázquez-Rowe et al. 2014). In addition a LCA was carried out for various anchovy products including canned, fresh, frozen, salted and cured (Avadí et al. 2014). In this article we undertake a LCA of canned sardines using the traditional method, a first LCA of a processed seafood product made in Portugal.

4.3 Goal and scope

We present a case study of canned sardine product based on data from a canning plant in Portugal that uses the traditional method (fish is cooked before being filled into cans). The method produces higher quality canned product, recognized for example, by the fish appearance when opening the can (Ribeiro 2013). Our intention is to analyze one specific canned product to find hotspots and potential improvements. The study is prepared within a consumer perspective and results are compared with other sardine and seafood products. It is case study that can be used in future studies to develop knowledge about the seafood canning industry.

The plant produces a variety of more than 100 products, with different fish, spices and sauces, representing around 2% of the total canned seafood production in Portugal (INE 2012). We selected the most important canned product in terms of value for the Portuguese canneries which is canned sardines in olive oil (Ernest and Young 2009). The functional unit is one kg of edible product of canned sardines which includes the olive oil. It corresponds to 120 g net weight per can, made of 85 g of sardines, and 35 g of olive oil and salt, at the gate of the plant (results for one can of sardines, corresponding to 120 g, and one kilogram of edible fish are in **Appendices**). We consider the olive oil as part of the total content of edible product because we assume that it is consumed and has remarkable tasting characteristics comparing with other type of sauces as for example tomato sauce. The life cycle inventory modeling is attributional, giving the potential environmental impacts attributed to the production system over its life cycle (EC-JRC 2010). The inventory is based on production from the canning factory data for 2010. The product selected, sardines in olive oil packed in 1/4 Club 30 mm aluminum can, represents 1.2% of the total production of the factory in that year. Capital goods for dispatch centers and canning factories were excluded on the basis of the long life span estimated, but also due to machinery complexity and lack of data. Following the standards to deal with allocation as stated by the LCA methodology (EC-JRC 2010), we could not find a way to avoid allocation. To split the burdens within the system, the potential environmental impacts were distributed among the different products and by-products based on mass allocation. Economic allocation was not used to avoid uncertainties related to the economic revenues because they are dependent on the factory and the season. The system and the main flows are summarized in **fig. 4.1**. By-products, such as heads and tails, are sent to a factory that produces animal feed. The assessment of the sardine by-products valorization and further use of materials are out of the scope of this article but by-products based on the mass allocation carry their part of the burden.

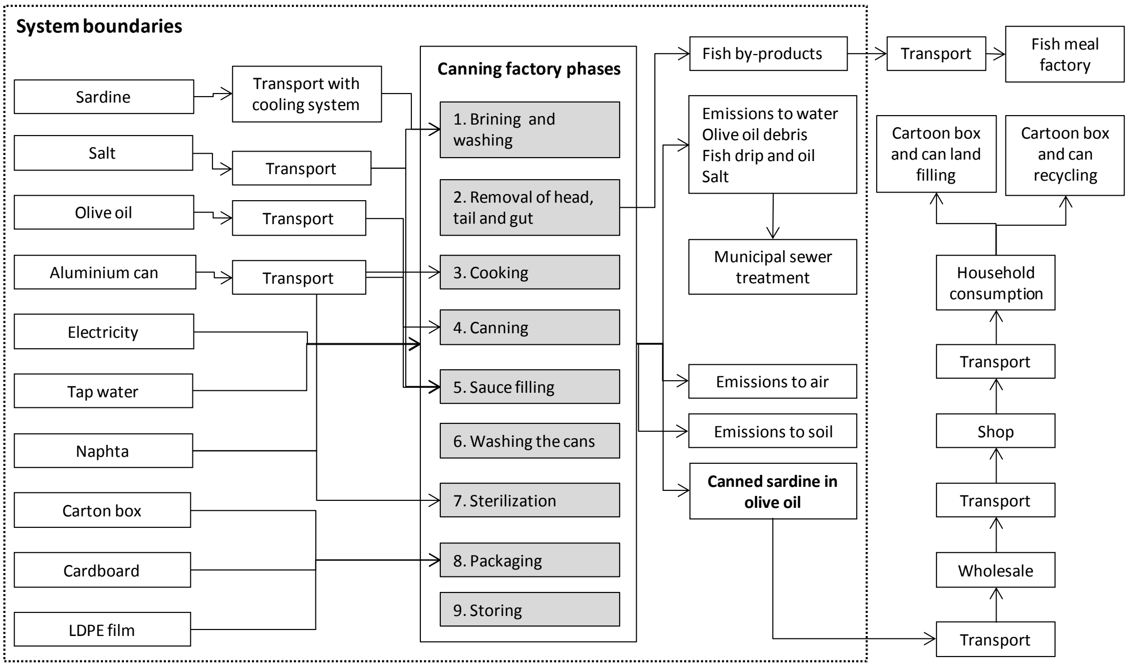

Figure 4.1 Flow chart and system boundaries of canned sardines in olive oil life cycle with the principal production phases (dotted lines define the system boundaries and boxes represent processes).

4.4 System description

The life cycle ends at the factory gates and the assessment constitutes a so called “cradle to gate” accounting study, with descriptive documentation of the system under analysis. The production system is made by three phases: the production of supply materials, their transport to the factory, and the canning process (**Fig. 4.1**).

The most important harbor in terms of sardine landings is Matosinhos, close to the factory in Póvoa de Varzim, and fish is transported by cooled trucks 31 km, from the harbor to the factory (INE 2012).

We only consider fresh fish in this study but frozen fish is also used sometimes (around 20%) (Leite 2012). Olive oil is purchased from a factory in Spain and refined with 2% extra virgin oil. The salt is sodium chloride produced in Portugal and is harvested from seawater through solar and wind evaporation.

In the canning factory, the fish is stored at 0 to 5 degrees until is used. The fish is brined in boxes with salt and water to strengthen the fish meat and adhesiveness of the skin. The sardines are size-graded to fit in the cans, heads and tails are cut, gutted, and washed with tap water, all manually. Sardines are placed in gridded trays and cooked. The loss of weight in this phase is approximately 8.2% of moisture and 5.2% of fat between raw and cooked product (García-Arias et al. 2003). After the cooking phase, the fish are cut again manually to fit into the cans. Fish residues, including heads, tails and fish with bad quality, represent around 49% of total sardine weight. Three fish are filled into each can and cans are placed in the conveyor to the sauce filling machine where olive oil is added. Cans are stickered with the cover part and washed. The end is joined to the can body by a double-seaming operation and the seam tightness is verified for quality purposes (Poças 2003). Cans are piled up in a container and heated in an autoclave at 118 ºC temperature during 45 minutes for sterilization. Finally they are codified and put into cartons in individual folding boxboards. The primary packaging is the can and boxboard, weighting 34 and 9 grams respectively. Additional packaging for transportation of the product is made by pallets, corrugated board boxes and low-density polyethylene (LDPE) film to wrap the trays and pallets.

The energy sources used at the plant are naphtha and electricity. All water used in the factory is drinking water. The filling machine debris is collected in water trays and around 70% of olive oil is reutilized through centrifugation (Leite 2012). The rest of liquid residues, with high concentration of fish oil and organic content from the cooking phase, are collected to the sewer and treated in the municipal sewage plant (Proença et al. 2000).

The system finish at the factory gate since the postproduction phases of canned products are assumed to have low importance. Cans do not need refrigeration and according to Thrane (2004), wholesale and retail phases are irrelevant. Among all the products displayed in stores, the energy that canned products should carry for illumination and air conditioning is negligible because most would come from freezers, cold storages and cold display counters, which none is due to canned products. Furthermore there is a major variability in the consumer phase influenced by the use of different products and consumer behaviors (Jungbluth et al. 2011). Since canned seafood does not necessarily need to be cooked, but it is sometimes, assumptions in the consumption phase can be inaccurate (Iribarren et al. 2010b).

4.5 Life cycle inventory and data collection

Assumptions were made about transports whenever we could not have primary information. All materials, activities and processes associated with the target product were identified (**Table 4.1**). The inventory was made with a combination of primary and secondary data. Primary activity data were used for those activities with production data published, which are: sardine, olive oil, aluminum and boxboard. Data for sardine fishing was taken from a study about a Portuguese purse seine fishery, which is the source of the fish used in the factory (Almeida et al. 2013). Additionally, we added figures of antifouling and boat paint manufacture per kg of fish landed from Vázquez-Rowe et al. (2010), since we were not able to obtain those values in the sardine study but they had a high contribution to ecotoxicity impact assessment results of purse seining. The olive oil data was taken from a recent Environmental Product Declaration (EPD) which includes the agro-industrial sector of Spain, Portugal and South of France (Monini 2012). Together these sectors represent approximately 47% of the world's production and have similar methods for obtaining olive oil (Monini 2012, Carvalho et al. 2012). Packaging and downstream phases from EPD were not considered since it comes as raw material to the canning factory. Aluminum production data was taken from the European Association of Aluminum (EAA 2012) and corrugated board for the secondary packaging from the European Corrugated Packaging Association (FEFCO 2012). Data for the production of naphta, electric energy, additional packaging and transports were taken from the LCA database Ecoinvent 2.0 (Frischknecht and Jungbluth 2007).

Table 4.1 Inventory data for the canning process.

Input	**Amount per FU**	**Unit**	**Transport distance (km)**
Sardine	1.5	kg	31
Salt	0.1	kg	30
Olive oil	0.3	kg	186
Electricity	0.2	kWh	
Naphtha	0.1	Kg	
Tap water supply	0.01	m^3	
Aluminium can (1 / 4 club 30 mm)	0.3	kg	145
Card board	0.1	kg	
Corrugated board	0.04	kg	
Plastic – LDPE	0.004	kg	
Output			
Canned sardine in olive oil	1	kg	
Non-edible fish by-products and losses	0.76	kg	
Emissions to water			
Water	0.01	m^3	
Olive oil lost	0.01	kg	
Salt	0.01	kg	
Phosphate (PO_4^{3-})	0.2	g	
Nitrate (NO^{3-})	59	mg	
Ammonia (NH_3)	47	mg	
COD (chemical oxygen demand)	20	g O_2	
Fats and oils	3.7	g	
Chloride (Cl^-)	11	g	
Sulfate (SO_2^{-4})	7.2	g	
SST (total suspended solids)	7.5	g	
Nitrogen (N)	0.8	g	

The transport of ingredients and materials to the canning factory is made by small lorries with 7.5 t total weight (Frischknecht and Jungbluth 2007). Transportation distances were estimated by means of road guide (ViaMichelin 2013). Sardines need cooling during transportation, which contributes to emissions both directly, through the energy required to power the system, and via leakage of cooling agents. An estimation of 1.3 liters diesel extra and 0.03 kg coolant per hour (equal use of both refrigerants R134a and R404a) for one container for the cooling system was assumed from Winther et al. (2009). All primary and secondary packaging is accounted for.

The main raw material for aluminium is bauxite, which is extracted from mines and processed into aluminium oxide to produce the metal through an electrolytic process (EAA 2013). The LCI dataset used corresponds to the production of 1 tonne of aluminium sheet and includes the recycling of the scrap and chips (EAA 2013). The aluminum sheets are fed through a cupping press, which stamps and draws disks into cans (Poças 2003). We consider an aluminum recycling for this phase of 28% of the aluminum sheets remnants from cans production (Madsen 2001).

4.6 Life cycle impact assessment

The data collected in the inventory are the basis for the impact assessment analysis which aims to evaluate the potential environmental impacts of the production system. The LCA was modelled in SimaPro Software Version 7.1.6 (SimaPro 2007) using impact assessment method CML-IA baseline (Guinée et al. 2001). The standard impact categories included abiotic depletion (ADP), acidification potential (AP), eutrophication potential (EP), global warming potential in 100 years (GWP), ozone depletion potential (ODP), marine aquatic ecotoxicology (METP), and photochemical oxidation potential (POP). Cumulative energy demand (CED) that calculates the energy used was also included (Frischknecht and Jungbluth 2007). The selection of impact categories was based on what was considered relevant and most widely used in previous LCAs of seafood products (Avadí and Fréon 2013). Results for fishery-specific impact categories, such as overfishing (OF), discards and by-catch, mean trophic level of landings (MTL), and primary production required (PPR) related to the sardine fishery are only relevant in the fishery phase and were included and discussed in Almeida et al. (2013). Results are also presented for other functional units (one can of canned sardines in olive oil and one kilogram of edible fish) to allow comparisons with canned products from other LCA studies (it has been included as **Appendices**).

4.7 Results and Discussion

4.7.1 Environmental assessment of canned sardine

The production of cans and olive oil dominate the impacts in all categories (**Fig. 4.2**). The same trend was seen by Vázquez-Rowe et al. (2014) who identify these two processes, together with the fuel consumption in the fishery as the main hot spots in the production of canned sardines. The production of cans is the most important contributor to CED, GWP, POP, METP, ADP and AP, contributing between 48% (POP) and 89 % (METP). The production of tinplate for the canning was responsible for the main part of greenhouse gas emissions in Vázquez-Rowe et al. (2014) due to its energy and land intensive extraction processes. The same result was obtained in other LCAs of canned seafood with tinplate cans, where the focus of the environmental improvements was in primary packaging (e.g. Iribarren et al. 2010a, Hospido et al. 2006). The can production is so important that assumptions made in the calculations of it have consequences for the environmental performance of the product. As an example, if the aluminum waste considered in the operation of cutting the cans from an aluminum sheet would not have been included, the total results obtained would have been lower in all the impact categories selected, from 25% lower for AP and METP to 7% to ODP. In this respect, improvements in the can production inventory are paramount to decrease uncertainty in LCA of canned seafood products.

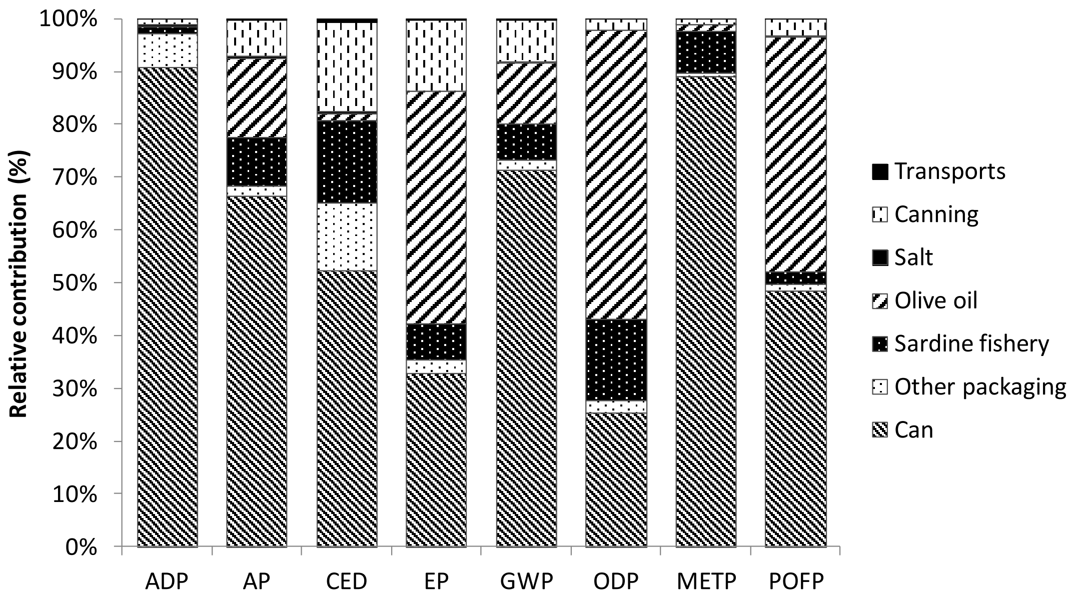

Figure 4.2 Process relative contribution for canned sardines in olive oil production.

The olive oil is the ingredient with highest environmental impacts, actually more important than the sardines and the can production for some impact categories. It is the largest contributor to ODP and EP, and almost is as important as can production in POP. The relative contributions vary from 44% for EP and POP, to 55% for ODP. The high importance of olive oil in these impact categories comes mostly from the upstream phase, of cultivation and the harvesting of the olives. Various fertilizers and pesticides are employed during the olive trees growth and procedures performed mechanically as pruning, irrigation and harvesting, require input of energy which contributes with emissions to air and water (Monini 2012). Especially the release of hydrocarbons and nitrogen oxides from these operations, highly contribute to POP and ODP. Alone the olive cultivation phase contributes around 86% to the POP and 93% to the ODP in the olive oil LCA (Monini 2012). Furthermore, only 20% of the fruit weight is extractable, so the remaining residue, made up by large quantities of seeds, pulp and residual oil, is released during the oil extraction phase, leading to emissions of nitrates and phosphates to the aquatic environment (Carvalho et al. 2012). Concerning EP, the production phase of the olive oil is responsible for almost 71% of the total emissions of olive oil (Monini 2012). Apart from the packaging, opportunities for improvements in canned sardines can also be found in the sauce spillage during filling, since around 7% is wasted and if it was reduced, less olive oil would be needed, which would reduce the overall impact.

Sardines, which are the main raw ingredient, had lower impacts per kilogram compared to olive oil for all impact categories, except for CED, ADP and METP. In fact the purse seine fishery is relatively energy efficient and although there were problems related to overfishing in 2010 (OF was 0.61), there was a poor relationship between GWP and stock condition (Almeida et al. 2013). Data for sardine is only from one study but there was not found variability between fishing vessels and they come from the harbor where the factory usually supplies sardines. Discards were primarily non-target small pelagic species but there was mortality of target species resulting from slipping; the seafloor impact was considered to be insignificant; landings had a low MTL of 3.1; and PPR was 15 kg C/kg (Almeida et al. 2013).

The canning process at the factory has the second highest relative contribution to the CED, after the production of cans. The traditional canning method implies more labour which could lower the energy demand. To compare both methods was not within the scope of this study, but would be interesting to understand further the importance of human labour for some environmental impact categories (Rugani et al. 2012). The use of naphtha as a source of energy in the factory was not an important factor for the environmental performance, still the use of cleaner energy sources would reduce emissions. In fact, the factory has just recently moved to a new location, where the use of naphtha will be replaced by natural gas (Leite 2012). With the same use of energy as before, this change would lower the GHG emissions by approximately 14% from the energy use at the plant (Herold 2003).

Other processes such as transports and salt production have an almost negligible relative contribution in all impact categories, transport distances are short and the quantity of salt is very low compared to the other ingredients. The total GWP was 7.6 kg CO_2 eq for the production of 1 kg of edible product of canned sardines in olive oil at the factory gate (**Table 4.2**).

Table 4.2 Absolute results in total and per life cycle processes for one kg of edible product of canned sardine in olive oil.

Impact category	Unit	Total	Sardine	Salt	Olive oil	Can	Other packaging	Canning	Transports
ADP	kg Sb eq	2.5E-06	3.0E-08	1.2E-08	0.0E+00	2.2E-06	1.6E-07	2.7E-08	9.5E-10
AP	kg SO_2 eq	3.8E-02	3.5E-03	1.3E-04	5.7E-03	2.5E-02	6.9E-04	2.6E-03	1.1E-04
CED	MJ eq	5.1E+01	7.9E+00	2.3E-01	6.3E-01	2.7E+01	6.5E+00	8.6E+00	3.4E-01
EP	kg PO_4^{3-} eq	1.1E-02	7.8E-04	6.6E-06	5.1E-03	3.8E-03	2.9E-04	1.5E-03	2.6E-05
GWP	kg CO_2 eq	7.6E+00	5.3E-01	2.0E-02	8.6E-01	5.4E+00	1.3E-01	6.0E-01	2.4E-02
ODP	kg CFC-11 eq	4.6E-07	7.0E-08		2.5E-07	1.2E-07	1.1E-08	9.9E-09	3.7E-10
METP	kg 1.4-DB eq	1.5E+04	1.2E+03	1.0E+00	1.9E+02	1.3E+04	9.8E+01	1.6E+02	4.3E-01
POP	kg C_2H_4 eq	2.5E-03	5.7E-05	5.3E-06	1.1E-03	1.2E-03	3.2E-05	8.0E-05	2.8E-06

4.7.2 Comparison sardine products at the retailer phase

The next phase after processing of products is distribution with transport to the wholesaler and store. Consumption at the household phase can have high variability depending on the consumption habits and for example, the transport to home, cooking, or storage, is made in combination with several other food items (Ziegler et al. 2003, Jungbluth et al. 2011). Compared to other sardine products, canned sardines are already cooked, and can be ready to eat or used as an ingredient in a dish, and one the other hand fish could also be consumed without heating (e.g. as sushi) although it is not common with sardines. Since there are many different possibilities in preparing fish and uncertainties related to this phase, we compare sardine products at the store, which is where the consumer makes the food choices. The comparison is made with fresh and frozen sardine products in order to analyse differences between the relative environmental impacts of sardine products at this point of the supply chain. A scenario was created as if our product was transported to a grocery store in Lisbon, Portugal.

We compare one kg of edible fresh and one kg of edible frozen sardine to one kg of edible canned sardine and the olive oil at the store. For fresh and frozen sardines we assume an edible rate of 62% of live weight from FAO (1989). During the freezing process, around 3% of the fish is wasted due to quality issues, and an average storage period of frozen sardines at the factory of 90 days was assumed (Schiek 2012). The transport of both fresh and frozen sardines was assumed to use maximum load of the truck and we accounted for extra fuel consumption for refrigeration and cooling leakage (Winther et al. 2009). At the store, we used data from Thrane (2004) for two months of storage for the frozen product scenario and two days of cooled storage for fresh sardines. For the canned product we did not consider any input from the retail phase. A product waste in retail of 5% for fresh fish and 1% for frozen fish was assumed (WRAP 2011).

Results per life cycle phase are found in **table 4.3Error! Reference source not found.**. Fresh sardines re the product with the lowest results in all impact categories except POP. Fresh sardines represent around 4% less GWP than frozen ones, and 91% less than canned sardines. The same result was obtained for the other impact categories (ADP, AP, CED, EP, ODP and METP) with the canned product representing much higher results, and almost seven times higher GWP compared to the other two products (**Figure 4.3**). Even if we had considered a cooking phase in the life cycle of frozen and fresh sardines, the results would have remained the same with regard to the comparison. The packaging is the main responsible for the large difference. Fresh consumption of sardines was also found to be the best scenario, with the lowest environmental impacts, in Vázquez-Rowe et al. (2014). Avadí et al. (2014) demonstrate that, in general more-refined products such as canned anchovy represent a much higher burden than less- refined products such as fresh and frozen.

Table 4.3 Results for one kg of edible product of sardines canned in olive oil, fresh, and frozen.

Impact category	Unit	Frozen	Fresh	Canned
ADP	kg Sb eq	1.4E-07	6.7E-08	2.5E-06
AP	kg SO_2 eq	6.3E-03	4.9E-03	3.8E-02
CED	MJ eq	1.7E+01	1.3E+01	5.2E+01
EP	kg PO_4^{3-} eq	1.4E-03	1.1E-03	1.2E-02
GWP	kg CO_2 eq	9.9E-01	8.0E-01	7.7E+00
ODP	kg CFC-11 eq	9.6E-08	9.1E-08	4.6E-07
METP	kg 1.4-DB eq	1.5E+03	1.4E+03	1.5E+04

POP	kg C_2H_4 eq	1.4E-04	2.5E-04	2.5E-03

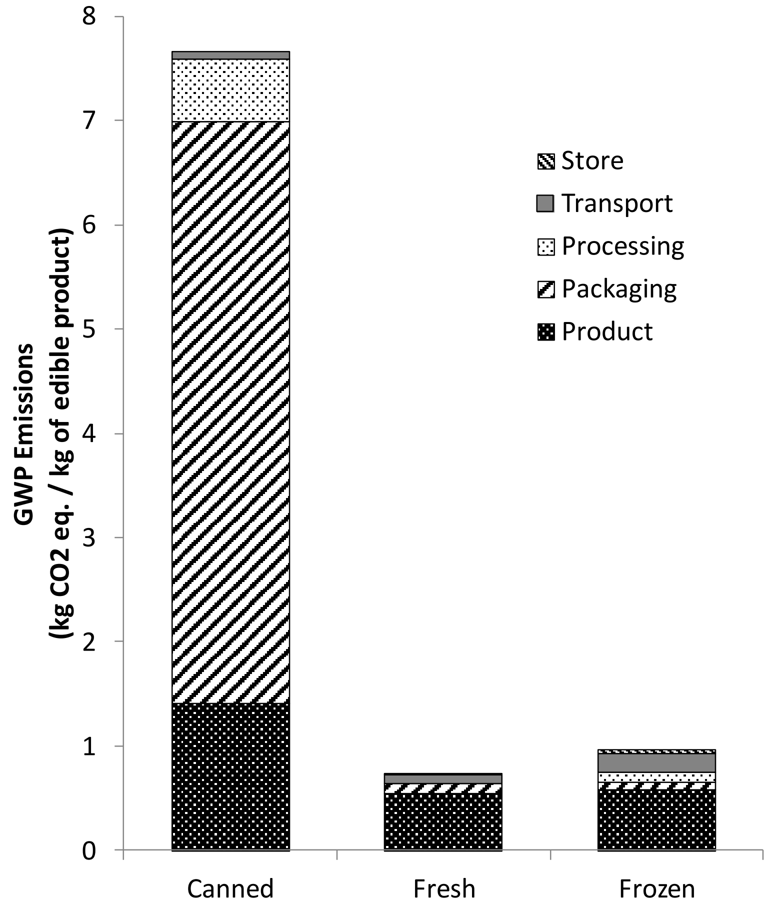

Figure 4.3 Comparison of GWP of one kg of edible sardine products at the store with the different life cycle phases. Canned sardine include olive oil and salt as part of the edible product.

Portuguese prefer fresh fish, 83% compared to other fish products, and have culinary habits of eating small pelagic and whole fish grilled (Cardoso et al. 2013). Fresh sardines could be a potentially sustainable food choice nevertheless transport accounts for 11 and 19% of total GWP in frozen and fresh sardines respectively, and only 1% in canned sardines. Most of the Portuguese canned sardine production is exported, mainly to the United Kingdom and France (Ernest and Young 2009). Transportation to these markets would have increased considerably the environmental impacts of fresh and frozen products. However, the increase the national distribution chain of fresh and chilled anchovy did not worsen the environmental performance of those products in comparison to the energy-intensive canned anchovy products in Peru (Avadí et al. 2014).

4.7.3 Sensitivity analysis

In order to study the influence of certain input parameters and methodological choices on the results, a sensitivity analysis was carried out. Due to the importance of primary packaging, the use of other packaging materials appears to be an option with a large environmental improvement potential (Iribarren et al. 2010a). Hospido et al. (2006) suggested that the environmental burdens of canned products could be reduced around 50% if using plastic instead of tinplate. Aluminum is more often used and it is one of the most recycled packaging materials, at a rate of 57% in Europe (Eurostat 2012). In the sensitivity analysis, we compare aluminum with other materials as tinplate, using data from the World Steel Association which assumes an overall recycling rate of 69%; and an alternative AMPET plastic packaging as described in Løkke and Thrane (2008), based on data from the Ecoinvent database. We assume that all the packaging alternatives are transported the same distance to the canning factory.

The GWP would be almost half (3.4 kg CO_2 eq) if using tinplate cans instead of aluminum and a little less (2.6 kg CO_2 eq) using plastic packaging (**Fig. 4.4**). The same trend can be seen in the other impact categories (**Table 4.4**). The highest reduction when using plastic instead of aluminum was 86% less in the impacts of METP due to the avoidance of the aluminum production. The same results were obtained in other studies as Løkke and Thrane (2008) and Hospido et al. (2006). Nevertheless the use of secondary data for the analyses could be a major improvement in future studies, using more specific data to avoid uncertainty. The results allow stakeholders to prioritize opportunities to reduce the environmental impacts even though, the possible changes when using plastic packaging regarding to shelf-life or taste, have not been investigated. The aesthetics of the product, mentioned by Vázquez-Rowe et al. (2014) when using plastic bags for sardines, is not a problem since the type of plastic package proposed by Løkke and Thrane (2008) has the shape of a can. It is a plastic packaging with the usually can appearance and canned mackerel in tomato is already marketed in this packaging by a Danish company (DuPont 2008).

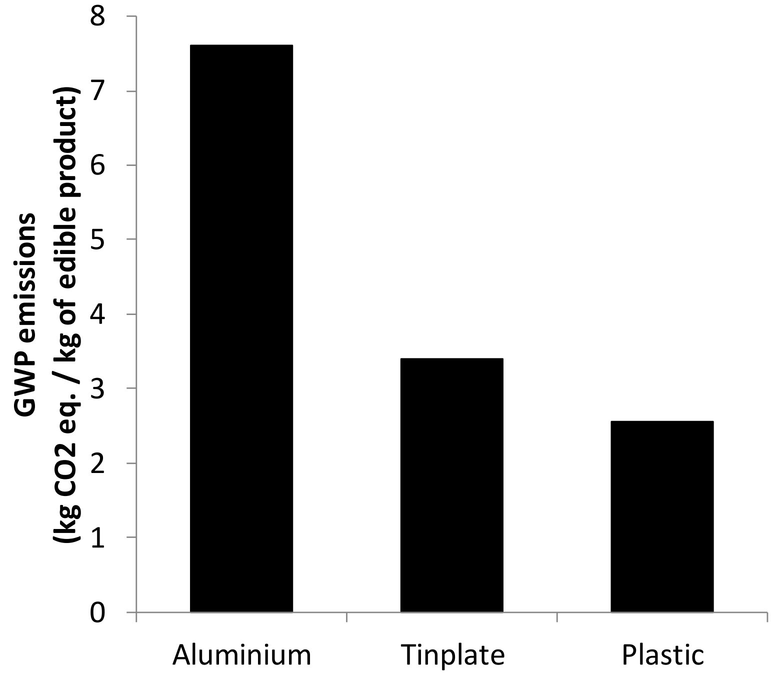

Figure 4.4 Comparison of the GWP of one kg of edible product of canned sardines in olive oil using different packaging materials.

Table 4.4 Results for one kg of edible product of canned sardines in olive oil with different packaging materials.

Impact category	**Unit**	**Aluminum**	**Recycled aluminium**	**Tinplate**	**Plastic**
ADP	kg Sb eq	2.5E-06	2.7E-06	9.6E-07	1.8E-06
AP	kg SO_2 eq	3.8E-02	2.9E-02	1.7E-02	1.4E-02
CED	MJ eq	5.1E+01	5.1E+01	4.1E+01	3.4E+01
EP	kg PO_4^{3-} eq	1.1E-02	1.1E-02	9.2E-03	8.2E-03
GWP	kg CO_2 eq	7.6E+00	5.8E+00	3.4E+00	2.6E+00
ODP	kg CFC-11 eq	4.6E-07	4.6E-07	4.0E-07	3.6E-07
METP	kg 1.4-DB eq	1.5E+04	9.9E+03	0	2.0E+03
POP	kg C_2H_4 eq	2.5E-03	2.1E-03	1.5E-03	1.4E-03

4.7.4 *Canned sardines compared to other seafood products*

The possibilities to compare canned seafood products are limited since studies use different system boundaries and functional units. Other canned seafood LCAs used tinplate instead of aluminum cans, or vegetables oil (e.g. sunflower) instead of olive oil (Hospido et al. 2006, Iribarren et al. 2010b). While most oils are obtained from seeds, the olive oil is obtained from a fruit, and the environmental impacts to produce it are four times higher compared to sunflower oil (Carvalho et al. 2012).

We re-calculated the GWP of the product, as it is marketed, one can, and as one kilogram of edible fish, to compare with data from other studies. The GWP result per can of sardines in olive oil is 0.9 kg CO_2 eq. The value is much lower than a recent study that obtained a GWP of 3.4 kg CO_2 eq. supplied by one can of sardines in olive oil with the same weight (Vázquez-Rowe et al. 2014). The difference can come from the sardine production since the GWP from Portuguese purse seiners was almost half of that from Galicia (Vázquez-Rowe et al. 2010, Almeida et al. 2013). Canned mussels, with a functional unit of a triple pack of round cans (129 g of canned mussel flesh and 120 g of sauce), had a GWP re-calculated to one kilogram of edible flesh product of 30.2 kg CO_2 eq. (Iribarren et al. 2010b). If we compare to one kilogram of edible fish of canned sardines in olive oil, with a of 10.9 kg CO_2 eq. GWP, it corresponds almost three times more.

It can be expected that canned seafood products will lead to higher environmental impacts than other seafood products at the processing gate, since they are already cooked and include the can. Other processed seafood products, as for example frozen and fresh cod or salmon fillets, have a GWP lower, ranging between 2 and 2.5 kg CO_2 eq/kg product (Ziegler et al. 2013). The same happens with cod products delivered to the consumer, which had a GWP that ranges between 1.7 and 4.4 kg CO_2 eq/kg product (Svanes et al. 2011). At the same time the GWP of canned sardines in olive oil was lower than frozen octopus harvested, processed and packed on the fishing vessel, with emissions of 7.7 kg CO_2 eq per kg of product (Vázquez-Rowe et al. 2012a). At the retail stage, meat products can show even higher differences of GWP, with ranges between 9 and 129 kg CO_2 eq per kg for beef for example (Nijdam et al. 2012).

The results are not strictly comparable in absolute terms but serve the purpose to discuss further on the environmental impacts of seafood production. A standardized approach, with a functional unit reflecting the complex nutritional properties of seafood, would definitely be useful to understand if differences between studies are related to less impacts coming from the ingredients, as sardine are sourced from a fishery with relatively low environmental impact (Almeida et al. 2013). Compared to other seafood, sardines have high edible yield from low weight. Furthermore sardines have soft bones that become edible after canning, facilitating the processing because there is no need to remove shells or bones, as it is with mussels or tuna (Aubourg 2001). The factory proximity to the harbor, gives easy access to fresh fish, which is believed that gives better quality to the end product (Ribeiro 2013). Another possibility is that it is a small factory, with the traditional method which needs more labor and time, but it might help at the same time to avoid waste in the production line. Nevertheless, this study is based on data from only one plant and for that reason we cannot generalize the results to the entire sardine canning industry.

The difference between environmental performance of seafood products depend on the fishery but also on the different degrees of processing and packaging (Vázquez-Rowe et al. 2012b). Additionally we can compare stock information and fishery-specific impact categories together with the traditional LCA impact categories, as MTL or PPR, which are both low for sardines (Almeida et al. 2013). Canned products do not need refrigerated storage and have a long shelf-life, which probably leads to relatively low impacts and waste in the post-production phase. An important improvement for the future sustainability of food systems is to reduce the food waste (Gustavsson et al. 2011). Canned sardines can lower the risk of food losses which are still not assessed along the post-harvest seafood supply chains (Stoner and Tyedmers In press).

Canned sardines preserve a small pelagic fish, with short shelf-life and difficult to process in large volumes. Due to market economics and free market access, the use of fish as such as sardines for direct human consumption competes with nonfood uses, as reduction into fishmeal feed, fish oil, or fishing bait (Tacon and Metian 2009, Vázquez-Rowe et al. 2014). If both terms of fishing and processing are based on a sustainable supply, highly processed seafood products, such as canned sardines, can increase the proportion of fish available for human consumption. The fat content of sardines, which enhances the flavor, varies according to the capture season (Aubourg 2001). In Portugal fresh sardines are eaten mostly during the summer, when they are more fat and tasty. In periods when there are sardine surplus captures or a low market demand, canning is a potential alternative to preserve sardines for food. This achievement can only be possible (Almeida et al. 2014). In the end, is the consumer who will make the choice but with such a high range of values between food products, more LCA studies are need to better understand food systems and advice consumers.

4.8 Conclusions

We obtained a GWP of 7.6 kg CO2 eq. for one kilogram of edible product of canned sardines in olive oil, corresponding to 0.9 kg CO2 eq. per can. Production of cans and olive oil are the two processes that have the highest contributions. The production of cans has the highest environmental impacts in six of the impact categories (CED, GWP, POP, METP, ADP and AP) and olive oil in the other two (ODP and EP). A potential improvement is to minimize waste of olive oil during the canning processing. Replacing the aluminum can by plastic represents an important improvement option. Frozen and fresh sardines represent much lower environmental impacts than canned sardines. Nevertheless, canned sardines provide edible protein of a small pelagic fish, difficult to preserve. If based on a sustainable fishery supply, it could increase the proportion of fish available for human consumption.

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Chapter 5.

Influence of consumer's knowledge towards more sustainable seafood consumption in Portugal

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5.1 Abstract

Portugal is a country with one of the highest seafood consumption per capita in the world. Our goal was to understand the Portuguese knowledge and attitudes towards seafood and relate it to consumers' environmental conscious. Using an internet-based survey we investigated the relation of socio-demographic variables to consumption frequency and how knowledge about seafood is associated with interest in different information when purchasing seafood products. Results demonstrate consumption of a high diversity of species. Tuna and cod are the top species related to convenience and food traditions. There is a preference to consume seafood mostly at home and prepared grilled. Differences between higher and lower knowledgeable consumers' related to seafood, show that the first ones have a more diversified use of species and high prevalence of small pelagic fish. The findings are influenced by the sample obtained, which over-represents well educated and higher income people. Moreover the self-reported consumption can be biased by individuals own perceptions and different seafood products. Better estimations of consumption frequency could result from asking more detailed information, as such as by species or meal occasions. Portuguese consumers have high knowledge about seafood but it is not necessarily related to sustainable choices. To help in sustainable seafood choices it might be more effective to promote existing habits based on Portuguese traditions that still are good alternatives for the marine environment. A higher consumer's knowledge does not necessarily mean more sustainability.

5.2 Introduction

The world demand for seafood is increasing and global supply grows three percent per year, outpacing the world's population increase (FAO 2012). Apart from the population rise, the growth is also driven by increasing per capita consumption rate, in particular from developed countries (Frid and Paramor 2012). Fish can be an affordable source of protein in some countries but access to seafood is highly unequally and in some parts of the world the consumption is still very low (FAO 2012).

Fish from capture fisheries are in some extent limited by overexploitation of stocks and widespread ecosystem impacts resulting from the growth and industrialization of modern fisheries (e.g. discards, depletion of predatory species, biodiversity loss) (Myers and Worm 2005, Branch et al. 2010; Johnsen and Eliasen 2011). In order to account for the limited supply from fisheries relative to the growing demand for seafood, aquaculture has grown more than any other agro industry, contributing to 47 per cent of all the aquatic food consumed in 2008 (Bostock et al. 2010, FAO 2012). But aquaculture has several associated environmental tradeoffs as in general it is dependent on wild fish for feed, especially in case of omnivorous species such as salmon and prawns, resulting in an inefficiency of resources use (Campbell and Pauly 2013).

The lack of confidence in the ability of governments to implement effective fisheries management raises the need to address production as well as consumption patterns (Khalilian et al. 2010). The consumers had become part of the solution and a sustainable seafood movement has risen with the goal to shift the consumer demand towards more sustainable seafood products (de Vos and Bush 2011, Mitchell 2011). Market-based tools, as awareness campaigns, boycotts that highlight particular problems, and seafood certification schemes, have been developed (Jaquet and Pauly 2007). Eco-labels have become symbols of sustainability and some supermarket chains and restaurants have committed to sell only certified sustainable seafood (Mitchell 2011). Still, the tangible impacts of these programs to change the market demand and production practices have been poorly evaluated (Jacquet *et al.*, 2010). Their potential remains uncertain since consumers are little informed about the different schemes principles and the influence of consumer’s choices in the supply chain operations is still poorly researched (James et al. 2011, Jonell et al. 2013).

Portugal has the third highest seafood consumption in the world considering only developed countries, with 57 kilograms per capita when the global seafood consumption is 17 kilograms per capita (Laurenti 2011). The Portuguese geography, make the fisheries and the consumption of fish products of extreme importance (Cardoso et al. 2013a). Fish is often described as healthy food and its consumption is generally promoted (Sirot et al. 2012). But given the toxic elements found in fish, such as mercury, a balanced diet is the wisest way to have health benefits associated to omega -3 fatty acids avoiding the risks of toxic contaminants (McManus et al. 2011; Cardoso et al. 2013a). Although Portuguese consume more than twice of the EU average and the recommended quantity by the World Health Organization, the government still advises to eat more fish (Westhoek et al. 2011). Therefore, a deeper knowledge of the Portuguese preferences and patterns of seafood consumption is warranted.

Research has shown that attitudes towards eating fish depend on the country or socio-demographic characteristics and are strongly related to regional factors and traditions (Altintzoglou et al. 2011, Van Dijk et al. 2011, Hicks et al. 2008). Moreover, the species consumed are linked to cultural traditions, which have been changing overtime (Apostolidis and Stergiou 2012). When trying to influence Portuguese consumers and to communicate the impacts of their seafood choices, target population needs to be identified and their specific preferences understood (Pieniak et al. 2008). Consumers in Portugal do not tend to connect their consumption choices to environmentally friendly actions and for example, Portuguese have the lowest purchase percentage of eco-labeled products within Europe (Finisterra do Paço and Raposo 2010, Koos 2011).

There are a number of studies on fish consumer behavior but not much about sustainability (Verbeke et al. 2007). To our knowledge, only Cardoso et al. (2013b) researched seafood consumption habits in Portugal and no survey has ever been done related to environmental issues. Most studies research on topics such as health benefits, product perception, perceived risks of fish intake, or seafood eco-labeling (Altintzoglou et al. 2011, Salladarré et al. 2010, Van Dijk et al. 2011, Birch and Lawley 2012). Little research has been done about the information consumers seek on seafood products and even for knowledgeable consumers can be difficult to take action (Pieniak et al. 2007, Whitmarsh et al. 2011). Researchers and practitioners need to find solutions to reduce environmental impacts of food but also aid to traduce consumer attitudes into behaviors (Verbeke et al. 2007).

The objective of this research project is to better understand the dynamics associated with seafood consumption of the Portuguese. With our research, we want to describe the consumption frequency, and attitudes towards seafood by Portuguese. We also want to evaluate consumers' knowledge by exploring the following question: How much knowledge do consumers have about seafood (objective knowledge), how aware are they about it (subjective knowledge) and how does this reflect in their choices? Finally, we want to determine consumer's interest on information about seafood products and to which extent consumers relate to environmental awareness and traditions.

5.3 Methods

5.3.1 Research Approach

To approach consumers, an online survey tool was developed (**Appendices**). Respondents were asked to answer questions regarding their consumption habits, knowledge, and perceptions related to seafood. The survey was administered using the online service SurveyMonkey©. It was sent to potential respondents through electronic mailing lists and social networks, with the web link address. A message was sent asking receivers to further disseminate the web link in their respective electronic mailing lists.

5.3.2 Questionnaire Content, Scaling, and Sample description

The survey was firstly piloted by 10 consumers to assess readability and assist in the content reliability. It comprised 21 questions divided into four sections: (i) frequency of consumption, (ii) knowledge, (iii) information interest, and (iv) socio - demographic information. The questions access was sequential and respondents were informed before starting that completing the questionnaire was estimated to take around 10 minutes. The survey was launched on 1 September 2012 and closed on 31 October 2012. In total, 1388 consumers replied to the survey. Respondents not living in Portugal or with information gaps were eliminated. After that procedure there were a total of 1240 validated questionnaires.

The first section about seafood consumption frequency (i) was self-reported on a 13-point scale that ranged from 'never' (1) to 'seven times per week' (13). The respondents were asked for the total frequency of seafood in general; and through two questions on how often they eat seafood both at home and out of home and at lunch or at dinner. Participants were also asked the individual consumption frequency for a list of 14 seafood species and for six different preparation methods. The species were chosen on the basis of consumption importance in Portugal and on apparent consumption data from Lopes (2002) and Willemsen (2003). For calculations the scale was rescaled to average weekly consumption frequency, ranging from zero to seven: 'seven times per week' was as 7 and "2 to 11 times per year" was 0.16 per week. The group of responses were added in the end to calculate a total fish consumption resulting from the sum of the different consumption species or occasions. In this way, two measures of indirect seafood consumption were obtained. Live weight seafood consumption was calculated using edible content ratios in James et al. (2011) and Vázquez-Rowe *et al.* (2013). Calculations were made with consumption frequency for one year and assuming a portion of 125 grams / week. The average portion was calculated from public health recommendations of 200 grams / week of fatty fish species and approximately 50 grams / week of lean fish, molluscs and crustaceans (Sirot et al. 2012).

In the second part (ii), consumers were questioned about their knowledge regarding seafood. Subjective knowledge, defined as a consumer perception of the amount of information they have, is a self-estimate of the knowledge an individual has about a particular subject (Flynn and Goldsmith, 1999). Four statements, consistent with measures used in previous studies (e.g. Pieniak et al. 2008) and adapted to suit the purpose of the study, were rated on a seven point Likert agreement scale with extreme values 'totally disagree' (1) and 'totally agree' (7): *I know a lot about fish and other seafood*, *my friends consider me as an expert on fish and other seafood*, *I have a lot of knowledge of* *how to prepare fish and other seafood for dinner*, *I have a lot of knowledge of how to evaluate the quality of fish and other seafood*. The objective knowledge was rated with true or false answers related to seafood production. Seven statements were asked: *Salmon is almost exclusively farmed; Fish is a source of omega-3 fatty acids; Cod doesn't exist in the Portuguese coast; Salmon is a fatty fish; All fish stocks are overexploited; At least two servings of oily fish per week is the recommendation for a healthy eating; The eyes of the fish don't demonstrate its freshness.* The level of knowledge was considered as the number of correct answers given by the respondents. The questions and the responses of the knowledge measure are presented in **Appendices**. The third section about information interest (iii), queried consumers to what extent they were responsible for purchasing or preparing food in the household (5 scales grade). A range of information appearing on the package / shelf about the product (price, health benefits, expiry date, recipes, catch method, catch date, catch origin, etc.) were presented to research consumers' interest in environmental criteria when purchasing seafood. It produced a set of 18 different categories (variables) that were rated on a 7-grade scale from not at all interested (1) to totally interested (7). The last part of the survey contained questions regarding socio-demography such as gender, age, nationality, residence, education, occupation, marital status, household size and income, and considerations about the residence area (size and distance from the coast).

5.3.3 Statistical Analysis

Data analyses include descriptive statistics to understand the overall distribution of respondents (as a function of gender, age, education level, etc.). One-way analysis of variance (ANOVA) was performed to determine statistical differences. The total frequency of seafood consumption was analysed as a dependent variable with other consumption variables, as different species, meals, places, preparation methods and level of interest for different information on seafood products when purchasing.

The scale used to measure seafood knowledge was multi-item. The reliability analyses were conducted with Cronbach's test to confirm unidimensionality of the items relating to subjective knowledge. The construct had an alpha value of 0.9, indicating internal reliability consistency and further analyses used the averaged constructed score. Objective knowledge was obtained on a true / false scale. The number of correct answers, which varied between 1 and 7, was accounted per respondent. Objective and subjective knowledge were analyzed with socio-demographic variables. Socio-demographic groups were described and differences were tested using Pearson chi-square test. Then, respondents were separated into two groups regarding their level of knowledge about seafood. When reported values for knowledge were below the estimated medians of the construct, participants were allocated to the low knowledge group; when were above the median, participants were allocated to the high knowledge group. The differences between level of knowledge, the dependent variable, and the seafood consumption as total and species frequency, number of different species, shopping and preparing responsibility, and interest on information about the seafood products, were analyzed with ANOVA. All correlations were considered statistically significant if *p* value was lower than 0.05.

5.4 Results

Our results indicated a sample of respondents that were on average 30 to 39 years, mostly women, higher educated, employed, with an income between 500 – 2000 € (**Table 5.1**). The household size varied between 1 to 4 people and approximately half of the respondents lived with children. The residence place was either rural or urban, with respondents living in villages, small towns, or large towns; and the majority lived on the coast (90% of the respondents lived less than 50 km far from the coast). Almost half of the respondents were highly responsible for shopping and preparing food in the household.

Table 5.1 Socio-demographic characteristics of the sample (%, n = 1240).

Characteristic	**Survey (%)**
Gender	
Female	66.9
Age	
20–29 years old	29.9
30–39 years old	42.7
40–49 years old	14.3
> 50 years old	9.5
Education level	
Secondary or lower	22.7
Higher	76.6
Work situation	
Employed	59.6
Student	24.8
Unemployed	8.7
Retired	2.3
Responsible for the household	0.5
Marital status	
Single (never married)	46.7
Married or living together	46.0
Divorced or living alone	6.5
Income	
<500€	3.1
501-2000€	55.4
>2001€	28.1
Household	
1 person	17.5
2 persons	29.3
3 persons	25.0
≥ 4 persons	26.1
Living with children	48.2
Living environment	
Rural area or village	20.5
Small- or middle-sized town	39.0
Large town	40.3
Distance from the coast	
Seaside (< 50 km)	89.9
Inland (> 50 km)	9.6

The frequency of seafood consumption was on average 3.3 times a week (**Fig. 5.1**). It was most often consumed at home (M = 3.5, SD = 2.8), almost twice as often as eating out of home (M = 1.3, SD =

1.8) ($p < 0.05$). People ate more frequently seafood at home for dinner than for lunch, and the opposite when eating out of home ($p < 0.05$). When we calculate the sum of the frequency of seafood consumption in the different occasions, it is even higher than the self-reported total frequency (M = 4.8, SD = 4.6). The most popular reported preparation methods of seafood were grilling and boiling. Baked and canned seafood had almost the same consumption frequency and fried was the least common way to cook seafood, being done on average once every 15 days ($p < 0.05$).

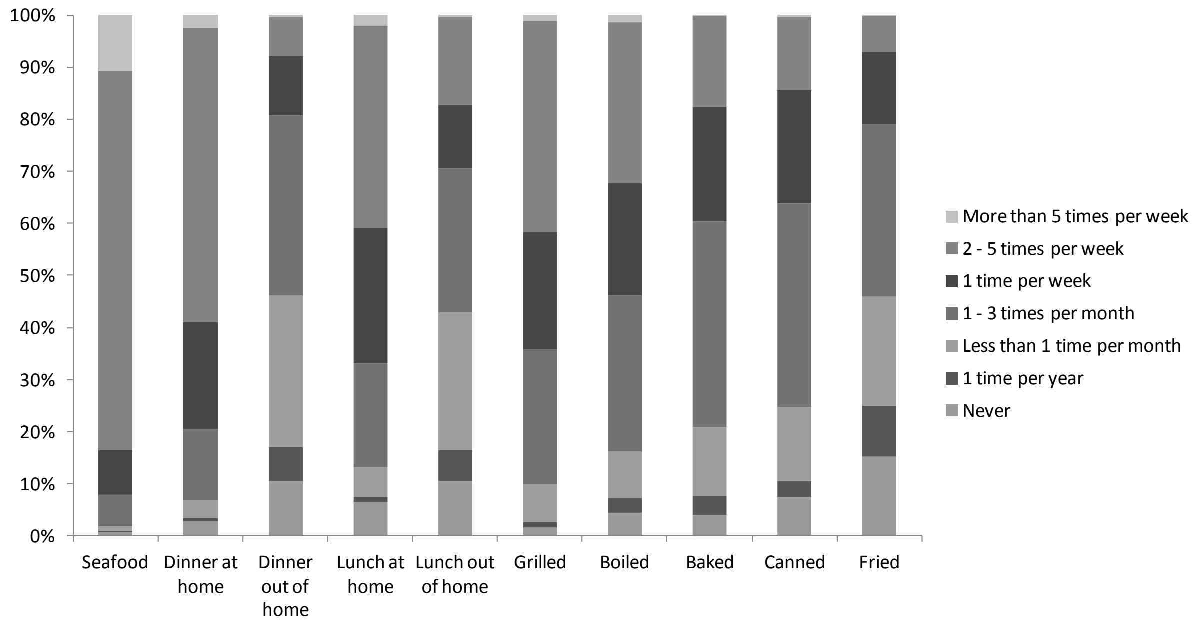

Figure 5.1 Relative frequency in occasions of seafood consumption in general, at different meals and different places; and in different preparation methods.

Tuna and cod were the fish most frequently consumed followed by hake and salmon ($p < 0.05$ for all species except for clams, mussels and cockle) (**Table 5.2**). The total seafood consumption frequency calculated by adding the 15 species items in the survey was 6.0 times a week (SD = 7.6). Tuna, cod, shrimp and clams had the highest total consumption, above 17 kg / year, after the conversion of consumption frequency to live weight.

Table 5.2 Frequency of seafood in consumption occasions per week (mean and standard deviation) and in live weight per year calculated with edible content conversion and assuming a portion size of 125 grams / week (* p < 0.05).

	Mean per week	SD	Edible content (%)	Live weight per year (kg)
Tuna *	0.8	0.8	42 #	12.1
Cod *	0.7	0.7	42 #	10.9
Hake *	0.6	0.8	53 ##	7.8
Salmon *	0.6	0.6	63 #	6.1
Sea-bream *	0.5	0.5	53 #	5.7
Horse mackerel *	0.4	0.6	53 #	5.5
Shrimp *	0.4	0.5	24 #	11.2
Sardine *	0.4	0.7	62 ##	4.3
Sea-bass *	0.4	0.5	53 #	4.7
Octopus *	0.3	0.3	68 ##	3.1
Chub mackerel *	0.3	0.5	53 #	3.8
Clams	0.2	0.4	14 #	11.7
Cockle	0.2	0.3	14 #	8.5
Mussels	0.2	0.3	14 #	8.2
Total	6.0	7.6		103.7

In James et al. (2011). We assumed the same edible content for sea-bream and sea-bass as mackerel, for shrimp as warm water prawns, and for clams and cockle as mussels.
In Vázquez-Rowe et al. (2013).

Both objective and subjective knowledge, which means the information about seafood consumers have and their own perception of the amount of information they have, were high. In a scale 1 to 7, objective knowledge was above middle point scale, with an average of 5.6, and subjective knowledge was 3.8. The most relevant characteristics to explain the knowledge about seafood were age, education, living with children, and marital status (**Table 5.3**) ($p < 0.05$). Results indicated significant correlations on gender for subjective knowledge, with males presenting a higher value ($p < 0.05$). Older people, more educated, not living with children, and with higher income, had a higher knowledge level on average, both subjective and objective. The opposite happened to respondents that were single or living alone. The place of residence and the proximity to the sea did not influence the way respondents were informed about seafood (no statistical differences).

Table 5.3 Characterization on subjective and objective knowledge about seafood (mean values and standard deviation) in a scale 1 to 7 (* p < 0.05).

Characteristic	**Subjective**		**Objective**	
n= 1238	***Mean***	**SD**	***Mean***	**SD**
Gender	*		-	
Female	3.6	1.5	5.5	1.1
Male	4.1	1.6	5.5	1.1
Age	*		*	
≤ 30 years old	3.4	1.5	5.2	1.2
> 30 years old	4.0	1.6	5.8	1.0
Education	*		*	
Secondary or lower	3.0	1.6	5.2	1.1
Higher	4.0	1.6	5.7	1.0
Living with children	*		*	
No	3.9	1.6	5.7	1.1
Yes	3.4	1.5	5.2	1.1
Regional distribution (%)	-		-	
Rural area or village	3.8	1.7	5.6	1.1
Small- or middle-sized town	3.8	1.6	5.5	1.2
Large town	3.7	1.5	5.6	1.1
Distance from the coast	*		-	
Seaside (≤ 50 km from the coast)	3.8	1.6	5.6	1.1
Inland (> 50 km from the coast)	3.4	1.5	5.4	1.2
Income	*		*	
<500€	3.7	1.6	5.0	1.1
501-2000€	3.7	1.6	5.5	1.1
>2001€	4.0	1.6	5.8	1.0
Marital status	*		*	
Single (never married)	3.5	1.5	5.4	1.1
Married or living together	4.1	1.6	5.7	1.1
Divorced or widowed	3.7	1.6	5.8	1.1

Respondents were in general very interested in information about the seafood products, all means were above the median value, 3.5 in a scale 1 to 7 (Mean = 5.6, SD = 1.6) (**Fig. 5.2**). Information related to expiry date (Mean = 6.6, SD = 1.0) and the price attained the highest interest (Mean = 6.5, SD = 1.1), and the feed used in farming (Mean = 4.6, SD = 2.0) and catch method in fishery (Mean = 4.5, SD = 2.1) had the lowest. Significant correlation was found between total frequency of seafood consumption and information for all variables ($p < 0.05$) except for: catch method, feed used, fish welfare, minimum size allowed, and genetically modified organisms.

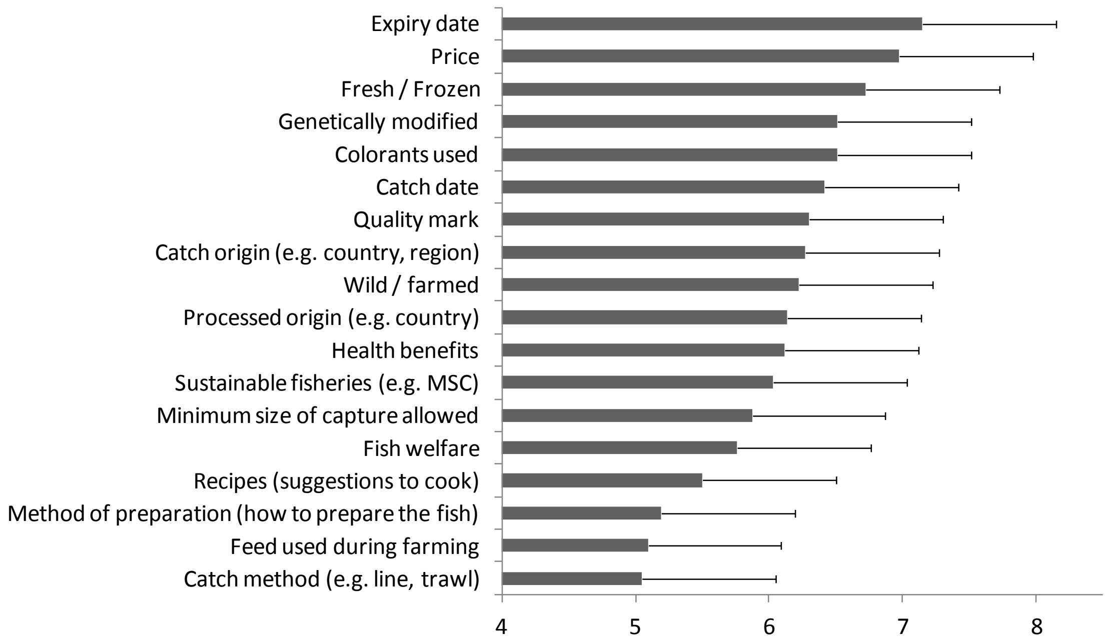

Figure 5.2 Consumers' ranking on the importance of information to purchase decisions when buying seafood (seven point scale).

The results for the two levels of subjective knowledge defined showed that they were related to socio-demographic characteristics such as gender, age, children in the household, income and marital status (**Table 5.4**). Consumption frequency was statistical correlated to the subjective knowledge level (**Fig. 5.3**). More knowledgeable consumers had higher seafood consumption frequency, and more often at home, comparing with lower knowledgeable consumers ($p < 0.05$). Also the responsibility for shopping and preparing food is correlated to knowledge ($p < 0.05$). Higher knowledgeable consumers shop and prepare food in a more regularly frequency. Regarding the diversity of species respondents reported to eat, there was a positive correlation between the knowledge level and the number of different species ($p < 0.05$), with an average of 12 different species for higher knowledge people. When we analyze the consumption differences per specie (**Fig. 5.4**), we have found significant differences between knowledge and species consumption for all except tuna, cockle and mussels ($p < 0.05$). Higher knowledgeable consumers have higher consumption frequency of all the species, with the highest difference found for chub-mackerel and sardine.

Table 5.4 Different levels of subjective knowledge (mean values and standard deviation) in a scale 1 to 7 related to socio-demographic characteristics of the consumers.

Characteristic n= 1238	High n = 623		Low n = 613	
	Mean	SD	*Mean*	SD
Gender				
Female	5.0	1.0	2.5	0.7
Male	5.3	1.0	2.4	0.7
Age				
≤ 30 years old	4.9	1.0	2.4	0.7
> 30 years old	5.1	1.0	2.5	0.8
Education				
Secondary or lower	5.1	0.9	2.3	0.7
Higher	5.1	1.0	2.5	0.8
Living with children				
No	5.1	1.0	2.5	0.7
Yes	4.9	1.0	2.4	0.8
Income				
<500€	5.1	1.1	2.5	0.7
501-2000€	5.2	1.0	2.4	0.7
>2001€	5.1	1.0	2.5	0.8
Marital status				
Single (never married)	5.0	1.0	2.4	0.7
Married or living together	5.2	1.0	2.5	0.8
Divorced or widowed	4.9	0.9	2.3	0.8

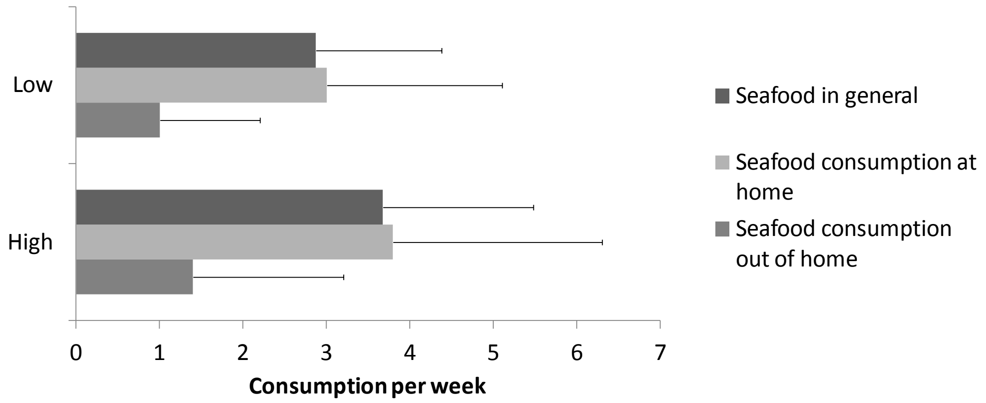

Figure 5.3 Means (standard deviation) of seafood consumption frequency per week per knowledge level on a seven point scale (all differences p < 0.05).

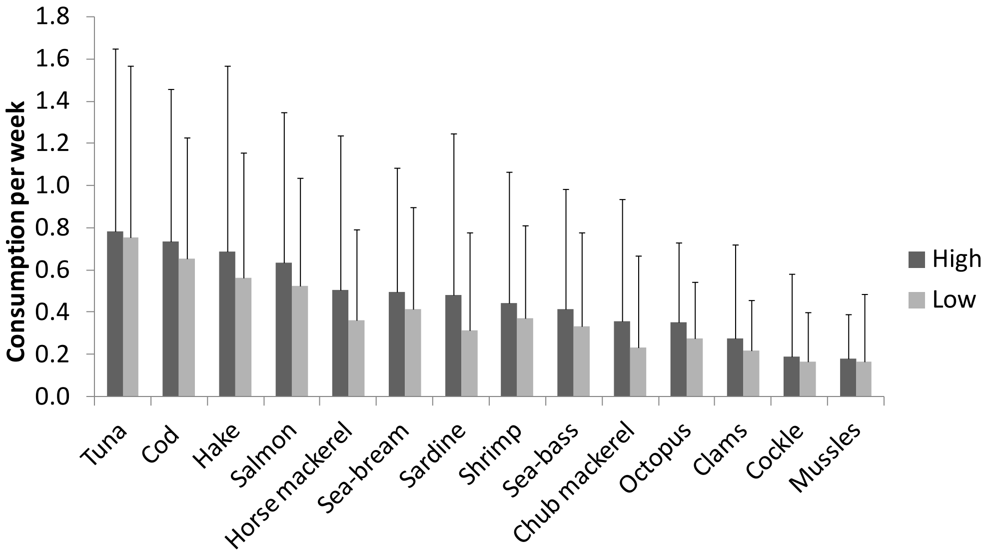

Figure 5.4 Means (standard deviation) of species consumption frequency per week per knowledge level on a seven point scale (* p < 0.05).

Finally, in what regards to the level of knowledge and interest in information about seafood production, there was a statistical significance between all (p < 0.05) except for “method of preparation” and “expiry date” categories. Respondents with higher knowledgeable were in general more interested in information about seafood products than lower knowledgeable consumers (**Fig. 5.5**). The only category that lower knowledgeable consumers have higher interest is on “recipes”.

“Recipes” had the lowest rate of interest for consumers with high knowledge and “catch method” for consumers with low knowledge.

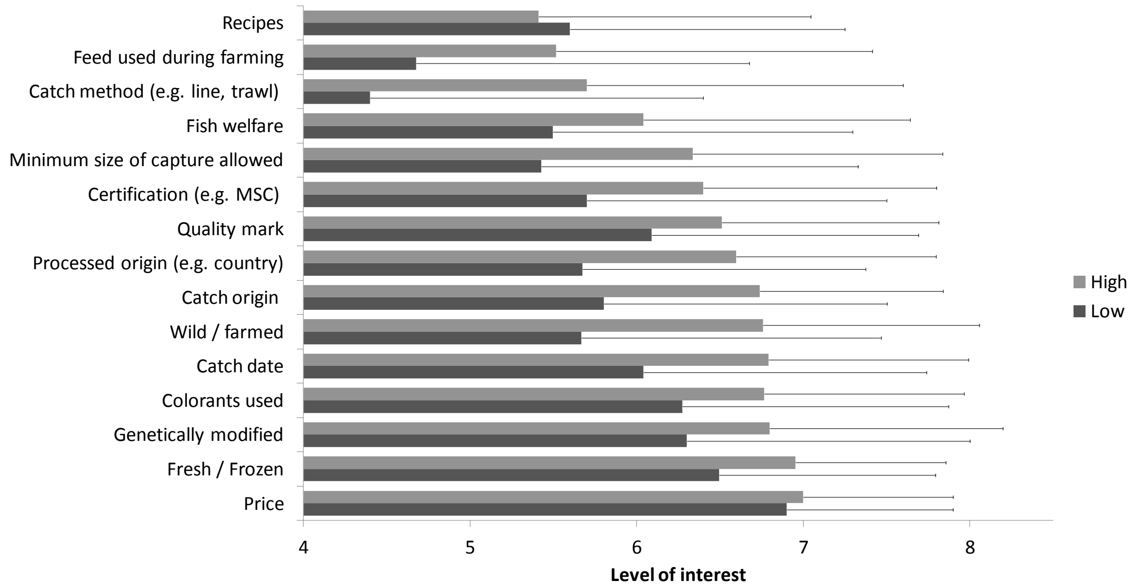

Figure 5.5 Means (standard deviation) of interest on information of respondents with high and low level of subjective knowledge on a seven point scale (all differences $p < 0.05$).

5.5 Discussion

The main finding of this study is that Portuguese consumers have high knowledge in general about seafood. Seafood is most frequently eaten at home and usually grilled. But Portuguese seafood consumption habits are changing and the traditional species (e.g. sardine) are becoming surpassed by more convenient ones (e.g. tuna). The higher knowledgeable consumers have a more sustainable behaviour, not because they are more interested in environmental issues, but as a result of being frequent seafood consumers of small pelagic fish and use a more diversified set of species.

We obtained a total consumption that represents a seafood meal every day during the week which is extremely high and exceed the recommended intake level of two servings of fish per week (Kris-Etherton et al. 2002). The high importance of seafood in Portuguese food habits is known, and it is in the same order as in Japan, one of the largest countries in terms of per capita consumption, where most of the consumers have seafood four or five times a week (Wakamatsu 2012, Cardoso et al. 2013b). It is a very high level of consumption especially compared to other countries, as for example Russia with 0.5 times a week (Van Dijk et al. 2011).

Seafood consumption habits have been described as very different among countries (Pieniak et al. 2007). Our results reveal that Portuguese eat most often seafood at home and for dinner, which can be related to a high level of cooking skills. High fish consumers, as Portuguese, are usually skilled to evaluate fish quality and prepare seafood (Brunsø et al. 2009). Grilling is the preferred way to prepare fish and it can be related to the importance of small pelagic fish in Portuguese fisheries, as for example sardine is the most landed species in Portugal (INE 2011). Those species are most easily cooked by grilling and Portuguese consumers' preferred whole fish rather than fillets due to both the culinary traditions and freshness, because parts of the body indicate fish degradation (Cardoso et al. 2013b).

The self-reported seafood consumption frequency is three times a week but the estimated consumption by the sum of the seafood frequency in different meals and places or the sum of individual species frequency, is five to six times a week. The differences between the self-reported and total estimate consumption can be due to underreporting of salt-and-dried cod, which is a special product since it is not habitually consumed fresh in Portugal as with other fishes. Moreover, to underreport consumption is an usual problem when estimating consumption frequency and for that reason better estimations could result from asking consumption in more detailed ways, as such as by species or occasions, as we have done here.

In any case, it illustrates the difficulty to assess an accurate consumption frequency and the bias resulting from individuals own perceptions (Lopes 2002). Using surveys to estimate consumption has other cautions as for example, if we calculate the self-reported consumption with the recommended portion converted into the edible part of seafood, gives a seafood *per capita* consumption of 51 kg live weight / year (Sirot et al. 2012). For the most extreme scenario, of six times per week, the seafood *per capita* consumption would be 92 kg / year much higher than the apparent seafood consumption of 57 kg / year given for Portugal (Laurenti 2011). Differences can be related to the fact that all seafood contains a high proportion of non-edible content and it varies between different products (James et al. 2011). For example, the most frequently consumed species are tuna and cod but regarding to the live weight, species as shrimp or clams have almost the same importance due to low edible yield. Nevertheless, the findings are in some way biased by the sample obtained, which as in other online survey studies, it over-represents well educated and higher income residents (Vanhonacker et al. 2013). And usually those groups have higher fish consumption and therefore they are people more devoted to respond to the questionnaire (Hall and Amberg 2013).

A remarkable feature of Portuguese seafood habits is the high diversity, including fish, shellfish, cephalopods, and crustaceans; mostly local seafood and related to the multispecies nature of Portuguese fisheries (Stewart et al. 2013, Moreno et al. 2014). The species mostly eaten are the same as in Cardoso et al. (2013b): cod, hake, and tuna; although in this study tuna was the species number one. Cod was reported as the most consumed fish in previous publications but habits might have changed in 10 years' time (Willemsen 2003). Salted-and-dried cod is very important in Portuguese traditions partly because it was available and cheap in the past (Garrido 2010). But products that are quick and easy to prepare change consumption traditions into convenience habits (Spinks and Bose 2002). The higher importance of tuna found here, consumed almost once a week, can be related to the fact that canned tuna is a convenient seafood product, easy and fast to prepare. Salmon, which comes in fourth place, is also the preferred fish for Japanese before tuna, revealing its growing production and subsequently lower market prices nowadays (Whitmarsh and Palmieri 2011, Wakamatsu 2012). Convenience, lower price and availability in purchasing place act as drivers and illustrate modern food habits. Important species in Portuguese fisheries, such as sardine and octopus, are not the most preferred. Such preferences can explain why almost two thirds of seafood consumed in Portugal is imported and the change of Portuguese seafood consumption habits through time (INE 2011).

Consumers are interested in information about seafood products and the level of knowledge and interest is related to a higher level of income and education. The presence of children in the household affects consumer's knowledge. The motivation to prepare food might be lower for people living alone and consequently the interest about seafood is also lower. We also found that consumption habits do not depend on the place of residence or the proximity to the sea, in opposite to Cardoso et al. (2013b) findings, which showed that seafood consumption patterns were affected by coastal *vs* inland location. Improvements in food supply chains nowadays make it possible to have different types of fish available all year round, especially in case of the most consumed species in Portugal, which usually are not commercialized fresh.

Higher seafood knowledge is related to higher consumption, often at home. Knowledge influences attitudes in shopping and preparing seafood and the number of species used. Higher knowledgeable consumers eat more seafood, especially small pelagic species such as chub mackerel and sardine and a more diversified number of species. Considering the current discussion about sustainable seafood consumption, the high consumption of small pelagic fish (e.g. sardines) and also the use of a diversified group of species, have the potential to be sustainable (Jacquet and Pauly 2007, Mitchell 2011). Such habits should be maintained since they make use of a diversified group of marine resources together with species from the low levels of the marine trophic web often used for feed in other countries (Tacon and Metian 2009, Olson et al. 2013).

Information on "Recipes" was showed the lowest rate of interest in the high level of knowledge consumers, meaning that people are not particularly interested in guidance on how to cook seafood. Indications on how to use the fish, as expiry date, seem to be more valued than knowing the catch method for example, which distinguishes the fishery and in some way the impacts on the environment. We hypothesize that Portuguese are not enough informed about fishery impacts on the ecosystems or either have not connected it with their purchase choices. As for the Japanese, environmental information is not very important for Portuguese consumers too and even though they have high knowledge about seafood, they are not aware of eco-labels and those products are not a priority to them (Wakamatsu 2012).

Consumption habits are driven by significant behaviours from the past, and increasing consumers' knowledge, has not a directly meaning of more sustainable consumer behaviour (Honkanen *et al*. 2005). As an example highly knowledgeable people, as educated biologists, do not make more responsible seafood choices (Bearzi 2009). From previous studies we know that quality, cooking, and product-related information are important attributes that highly influence seafood choices (Spinks and Bose 2002, Honkanen and Olsen 2009). And cultural factors, such as recipes and food traditions, are shared and influence the individual preferences within a nation (Apostolidis and Stergiou 2012). To approach the consumers' and change consumption patterns, one must take cultural differences into account and understand the degree to which knowledge and educational level influence consumers' comprehension of environmental messages (Honkanen and Olsen 2009). Buying eco-labelled products is one dimension of consuming sustainably. Purchasing local or from small scale sources are examples of alternative behaviours (Olson et al. 2013). Other important dimension for the sustainability of seafood supply is fisheries management. In case of well managed fisheries, the utilization of less popular fish could be promoted as more sustainable choice (Mitchell 2011).

5.6 Conclusions

Portuguese seafood consumption is high and with a high diversity of species. People buy and prepare seafood often, mainly at home. Convenience seems to have changed seafood consumption habits in Portugal. Tuna, including canned tuna, and cod, as salt and dried cod, are the most consumed seafood. Portuguese have relatively high knowledge about seafood. The more sustainable seafood choices are not influenced by environmental concerns but to some Portuguese seafood habits, such as a diversified use of species and use of small pelagic fish, which are potentially sustainable. Certification schemes that help the consumers in the sustainability of their choices are useful in some countries, where there is demand for eco-labelled products (Koos 2011). In others, such as Portugal, it might be more effective to complement it by promoting food traditions that still are good alternatives for the marine environment.

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Chapter 6.

General discussion and future perspectives

You must be the change that you wish to see in the world.

Mahatma Gandhi

6.1 Main findings

Seafood is nutritionally important although, even if most dietary recommendations say that people should eat more fish; this is not applicable in Portugal. Traditions, religion, and politics shaped food habits and this explains the high seafood consumption in Portugal (**Chapter 2**). Such high seafood consumption has consequences for the environment, since seafood supply worldwide is constrained by the ecosystems productivity. From the economic point of view, the higher importance of fisheries on a national and global scale, relates to higher importance of imports from an industry that continues to fulfil the demand with seafood from all over the world. Nevertheless, health concerns related to the risk of toxic substances intake above safety levels, such as mercury found in large predatory fish (e.g. tuna), should be a concern among Portuguese.

Among the seafood most consumed by Portuguese, sardines are the most important fish landed and consumed in Portugal. The carbon footprint of sardines in the studied purse seine fishery (**Chapter 3**) is low when compared to other seafood products. The fishery has lower environmental impacts compared to other fisheries, related to low fuel use and biological impacts, mainly due to the schooling composition of small pelagic fish species. However a long-term management is needed regarding to stock variability, by-catch, and discards from slipping, which may be substantial. The large differences in environmental performance in the purse seine fishery found between years, and indications that variability could be even larger between months, suggests how important it is to track fisheries performances through time. The biological impact categories were an important complement for the LCA results to provide a complete picture of the environmental impacts of the fishery. Even though those biological impacts are difficult to quantify but without them, results would have been misleading.

The biological categories and the time analyses were important to the accuracy of the seafood LCA study. Useful information for fisheries management was also obtained related to the fact that stock condition and energy efficiency were not correlated in this fishery. It means that even for an efficient fishery, there is need to verify the stock status. Moreover contrary to most perceptions, no difference was found in fuel use between large and small vessels but catch composition was different. Large vessels seem to be more efficient because they catch large quantities. Even though small vessels operate close to the coast, they are more versatile and to catch different species can also result in different impacts on the ecosystem.

Chapter 4 is a contribution of LCA information about canned seafood processing, which can supply edible protein from fish that is difficult to preserve making it possible to use for human consumption when other options are not available. The environmental cost of canned sardines in olive oil was compared to frozen and fresh sardines, and the GHG emissions are almost seven times higher per kilo of edible product. Between different sardine products, the best choice for the environment would be chilled sardines, even though frozen sardines would not represent such a big difference. Canned sardines do not need refrigeration during transport or storage but, when compared to other sardine products consumed in Portugal, have much higher environmental impacts. It is mostly due to the aluminium cans related to their production energy and extraction of raw materials needs. The main actions to optimize the environmental performance of canned sardines would be to replace the primary packaging, by using for example plastic packaging rather than aluminium. Furthermore, the LCA results showed that the olive oil is important for the overall assessment of canned sardines in olive oil. There are high environmental impacts from cultivation and harvesting of olives and to diminish the olive oil losses would be also an important improvement.

The survey to Portuguese consumers made in **Chapter 5** verified that they have relatively high knowledge about seafood. Nevertheless higher knowledge does not necessarily means more sustainable choices. The differences found between higher and lower knowledgeable consumers' were that the first ones have a more diversified use of species and high prevalence of small pelagic fish. Therefore to help in more sustainable seafood choices it might be more effective to promote existing habits, based on Portuguese traditions that still are good alternatives for the environment. Tuna and cod are the top consumed species related to convenience and food traditions and there is preference among Portuguese to consume seafood mostly at home and prepared grilled, which reveals the cultural differences in seafood habits within countries. Nevertheless, these differences are important for communication purposes to provide efficient messages that can reach and be clear to the consumers.

6.2 Implications and perspectives for seafood consumption in Portugal

Consumers should be aware of the consequences of their seafood choices and their responsibility at the end of the supply chain. As there is a growing disconnection between producers and consumers, they need information and tools that help making responsible choices because. Fisheries management is not completely accomplished and scientific advices are not always followed by governments. Furthermore, seafood is to a greater extent imported from other parts of the world, whether fish has a role as local food security, or from stocks that we still do not have enough knowledge. Cod and tuna, both very important in the Portuguese seafood consumption, are species with stock with critical situations. Cod stocks for example are still recovering from intensive fishing during many years. Cod is supplied from North Atlantic stocks and, although the Norwegian Northeast Arctic cod is in good condition and MSC certified, some other cod stocks are considered vulnerable by the IUCN (e.g. Hornborg et al. 2013). Furthermore high seafood consumption might impose health risks related to the intake of toxic substances, as it is the case for high tuna consumption but this issue has not been addressed in Portugal at a policy level (**Chapter 2**).

Chapter 2 tried to answer the question "Why do Portuguese eat so much seafood?" in order to understand if changing consumers' habits to be more sustainable would be worthwhile. The analyses carried on **Chapter 2** shown that Portuguese habits are shaped by different drivers that changed through time and that some of them are not as prevalent as before (e.g. religion), which gives room to properly investigate what would make more sense in trying to influence consumers habits. Consumers adapt quickly to changes and appear to develop new skills and acquire new tastes about seafood (Scholderer and Trondsen 2008). It is the case with the recent global popularity of sushi. If it is possible to change consumers' habits towards sustainability, the next question is: "How?" As we have seen with **Chapter 5**, it is suggested that different solutions need to be developed in different contexts. Food traditions vary from country to country and it is necessary to take into account differences related to environmental, economic, and cultural traits. The consumption pattern is different regarding for example, species and preparing modes, which indicates that communication need to be adapted to those patterns. Seafood consumption is not a problem in most of the European countries, where the main issue for sustainable food consumption is related to meat reduction (e.g. Vanham et al. 2013). However, recommendations need to be developed at the country level, and for Portugal it might be needed to include the seafood consumption.

Portuguese seafood habits are in part sustainable from the perspective that they have a diverse amount of species are from low trophic levels (e.g. sardine, chub mackerel, horse mackerel) (**Chapter 5**). The sardine LCA study reinforced the role of sardines as a sustainable choice among Portuguese habits of eating small pelagic fish (**Chapter 3**). Sardine is the only fish under MSC certification produced in Portugal, and although it was suspended due to low recruitment and high fishing mortality, it was reinstated in 2013 under a management plan (ICES 2012). Nevertheless Portuguese seafood diet relies on many different species apart from fish (**Chapter 2, 5**), which is a way to avoid pressuring the stocks and the risk of intake of toxic substances from seafood. However every environmental judgement depends on what we compare: stock, trophic level, fishing gear, or even to other food as meat and vegetables. Moreover LCA results are variable within the same group of food depending on the assumptions and systems boundaries considered (Nijdam et al. 2012). The LCA methodology is not accurate and prepared to make direct comparisons between studies. Fish has in general a better environmental performance in comparison to meat, and for example sardines represent a reduction of 88% GWP in comparison to broiler chicken, and even higher difference for pig and beef production (González-Garcia et al. 2014) However, there are restrictions due to stocks management and biological impacts on the ecosystems that limit the raise of seafood from fisheries and aquaculture production.

At least, a seafood consumption that is in accordance to human nutrition needs would be a wise choice, which means a reduction in the Portuguese seafood consumption (**Chapter 5**). Sustainable seafood is not about finding more fish to feed people but instead, about nourishing better with the fish that we already use. To use seafood to human consumption as much as possible and move, to burden further down the food chain to species like clams and mussels, or even better to vegetables and crops. Although small pelagic species can be more sustainable as a seafood choice, they also have the problem that rapidly deteriorates and catches correspond to large volumes of fish (Tacon and Metian 2009). Processing small pelagic species, as in canned sardines, can be an alternative to preserve fish for human consumption preventing that it is wasted or used sub-optimally as feed, resulting in a more efficient use of animal protein (**Chapter 4**). Nevertheless, it has a higher cost for the environment compared to fresh or frozen fish, which raise the importance of canning as an option to preserve fish when the other options are not possible or whether there is need for a long transport.

The idea that consumers' need more information to make sustainable choices (e.g. Brécard et al. 2009) might not be totally applied to Portuguese consumers. The results from the survey cannot automatically be assumed to be representative across the population as a whole but it is suggested that more knowledge did not directly mean more sustainable seafood choices (**Chapter 5**). Portuguese in general do not translate their environmental concerns into actions and their motivation to environmental friendly habits is often related to economic benefits associated with it (e.g. saving water) (Finisterra do Paço and Raposo 2010). Nevertheless consumers can participate in multiple ways to change habits as for example transforming food consumption towards a more plant-based diet (Dagevos and Voordouw 2013). There are different approaches to implement this transition and examples of successful strategies. It is possible with the occasional inclusion of a vegetarian day (Schösler et al. 2012) or with positive rewards to change individual habits, as it was seen with the "fun theory", when people choose to make environmental friendly behaviours based on the enjoyment that it gives back[11]. To some people not only environmental but ethical arguments about food consumption (e.g. moral duties to developing countries or animal welfare), could also lead to an optimistic view that they are supporting a sustainable food supply (de Bakker and Dagevos 2012).

6.3 Sustainable diets

Seafood is only one ingredient in diets and a sustainable consumption is not achieved if other food choices would result overall in worst impacts for the environment. The sustainability in seafood consumption needs to be included within a diet with low environmental impacts which contributes to food and nutrition security and to healthier life for present and future generations (Burlingame and Dernini 2012). For that reason the diversity of dietary patterns needs to be exploited to define healthier and sustainable food habits (Guyomard et al. 2012). Promoting those habits together with increased knowledge on the impacts from seafood production, could improve the SCP of seafood in Portugal and in the rest of the world. The public health and environmental impacts of food are in broad alignment with reduction of animal protein consumption (Aston et al. 2012, Scarborough et al. 2012, Vanham et al. 2013) and major synergies between choosing healthier and more sustainable diets can be applied also to seafood. More sustainable seafood and a reduction of some species intake are safer guidelines since large or long-lived fish tend to accumulate larger amounts of mercury and are more susceptible of overfishing (Gerber et al. 2012). At the same time there are toxins that accumulate in other type of seafood, as for example farmed salmon (Hites et al. 2004) or cephalopods (Cardoso et al. 2012), and therefore the replacement of animal protein by plant protein could be applied to seafood in high seafood consumption contexts, as it is the case in Portugal.

[11] www.thefuntheory.com

The Mediterranean diet for example, with abundance of olive oil, fruit, vegetables, cereals, and low quantities of meat and dairy; is a sustainable diet that offers considerable health benefits and respects the environment (Sáez-Almendros et al. 2013). Although the Mediterranean diet considers 13.5 kg average annual fish consumption (van Dooren et al. 2014), which is much less than the Portuguese average with 62 kg per year (FAO 2010). Moreover Portuguese consumption exceeds probably in 66% the recommended daily intake of omega-3 fatty acids from fish (Cardoso et al., 2010). A simple, feasible and healthy recommendation to Portuguese sustainable consumption would be to diversify and reduce seafood. At the present there is not any type of recommendation applied to the Portuguese food habits.

6.4 Final considerations

Efforts to improve the sustainability of seafood production require an efficient use of resources, promoting fisheries or forms of aquaculture that generate greater edible returns, with lower GHG emissions and environmental impacts. Governments could be more active, implementing reforms and promoting initiatives to produce sustainable seafood, but a responsible use of marine resources needs to be done in both directions: production and consumption.

Despite many initiatives from the sustainable seafood movement, there is no common or accepted definition of “sustainable seafood consumption”. If scientists cannot define it, it is even more difficult for citizens to make responsible seafood choices. In addition, fish comes from all over the world and it is almost impossible to gather such broad knowledge about different fishing stocks, gears, and management plans, depending on the country. Seafood production is a very complex issue and citizens need help to understand the environmental impacts from their food choices.

In that sense, LCA is an important methodology to apply when there is need to quantify and aggregate environmental impacts from seafood production. However, the methodology has limitations regarding to the biological impacts and metrics to compare different food systems (e.g.

land use versus seafloor impact). Moreover it is questionable how far it can be improved to weight more information, as for example the trophic level or animal welfare issues. LCA studies are costly, and even though some companies started to be interested in carbon footprints of their products, it is not possible to analyse all the seafood products that exist on the market. Nevertheless LCA results give a broader perspective of the life cycle and can be complementary information to other mechanisms such as certification. LCA results are useful as a decision instrument or for research purposes, but maybe not directly to consumers. The information could be used in seafood as a descriptive label (e.g. EPD), which does not have to be on the product but can be accessible, letting the consumers to verify and to judge sustainability, even behind certification schemes or other market-based mechanisms.

More important than deciding what it is sustainable or not, is to give “tools” that can help consumers to make responsible choices. The information about fisheries and seafood production can also improve interaction between industry, consumers and market regulators. These interactions are opportunities to find less popular fish from stocks in good performance. Promoting their consumption could benefit the profit from fisheries landings and improve the use of animal protein from aquatic species to direct human consumption. Nevertheless the consumer needs cannot be taken for granted. Sustainable consumption requires interdisciplinary research and consumer studies to verify which drivers are behind the habits and how to communicate efficiently to consumers. Provision of ever more or either too detailed information entails a risk of information overload and as important as more information, is to understand what type of information is needed. In that way to communicate about sustainability issues at a local level entails more probability that the message reaches the goal, as it was seen for the case of Portuguese seafood consumers.

To approach consumers with beneficial messages regarding to health, taste, or price, can have equal or even better results than only environmental messages. If it is possible to have a balance between price and sustainable seafood, it could result in strong possibilities for SCP of seafood. Consumers seem to be unaware of the fact that they eat more animal protein than actually required which is neither good for their health nor for the environment. In this way, there is need of appropriate dietary recommendations, balancing nutrient intake versus harmful exposure and cost-benefits from seafood consumption. Relating those concerns could be more prevalent to change Portuguese consumption habits in the direction of more environmental choices.

Governments that pursue to improve fisheries management can at the same time develop programs with educational campaigns at schools and recommendations with clear messages that match environment, health and cultural habits. Nevertheless to protect the environment, citizens cannot only rely on governments' policies or market-based mechanisms because important achievements are to improve practices of consumption. It is simpler and achievable by everyone to change customs (e.g. include a vegetarian meal once a week or reduce seafood consumption) than reconsidering all seafood consumed by a person. Nonetheless an approach that combines the different instruments would be the most effective (e.g. policies, which is a slow process; certification; tax incentives; awareness, with communication campaigns; and education).

Consumers are definitely allies and agents of change to sustainability. The most important part to take SCP of seafood is to understand how to approach consumers, especially those who are not aware of the responsibility of their choices, as it is the case of Portuguese seafood consumers.

6.5 Future research

Much research remains to be done to improve knowledge about SCP of seafood. Regarding to LCA studies would be needed to establish agreements with companies to obtain data that is a critical part in the LCA methodology. More data would cover gaps that still exist related to seafood production, processing, transporting and food packaging. More LCA studies would allow comparing fisheries, gears and products. Aquaculture, as an important and ever growing seafood source, needs more studies to cover the many different aquaculture production systems worldwide and to inform the consumers. There is a need to have a wider and better analysis of Portuguese fisheries in order to have an overall scenario about the environmental consequences of Portuguese seafood consumption. Nevertheless, due to high level of seafood imported in Portugal, and the high trade of seafood worldwide, it would be useful to get ever more LCA studies to have a broad picture of the seafood supply. Moreover there are benefits of working together with industry and stakeholders, as for example opportunities to test improvements or to work at a local level, instead of a national or international scale.

The canning industry has an important role to preserve seafood that is becoming more valued due to the future raise of the world population and the environmental impacts from food production. For that reason it would be useful to obtain a better picture of canned seafood production, developing LCA studies about other canned products. Nevertheless it would be important to collect data from other canning industries and methods based in modern technology in order to compare them with the study done for canned sardine in olive oil, based in the traditional method.

Certification schemes and other market-based mechanisms need to be analysed and tested regarding to their credibility and sources used. Their messages need to be compared and verified continuously because they need a constant up-dating. The more they are verified, the more consumers can trust and rely on them. It would be important to understand at what level certification schemes function better (e.g. national or international) and if it is possible to combine certification with LCA results.

Communication is a key area to find what type of information is relevant and understandable by everybody in order to change the consumption habits. The consumer survey done is a contribution to the knowledge about seafood consumption in Portugal but it would be interesting to combine findings from online surveys with other methods such as interviews, or focus groups analyses. Investigating indirect indicators, as for example restaurants menus, can bring different perspectives to the discussion on how to change for a SCP of seafood. Because people make different choices in a survey than they would make in real-life, it would be useful to establish collaboration with wholesalers to test different messages or labels in situ and on different products (e.g. frozen, chilled or canned seafood). Nevertheless, it is the combination of different methods that give a wide perspective about the food habits and patterns.

Much is still needed to attain a sustainable consumption of seafood both in Portugal and worldwide. Although there is not a concrete definition for SCP of seafood, it is a concept that needs to be adapted to different contexts, stakeholders, and continuous changes. This thesis has been a small contribution to that challenge helping to understand how complex it is to deal with the variability of natural systems coupled with the intrinsic characteristics of human systems. We have a long way ahead but no matter how difficult it might be, sustainability is the answer.

6.6 References

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Appendices

Appendix 1

Table I Inventory for fish landed in Portugal by purse seiners. Values per FU (standard deviation) of fish landed for the overall fleet and for different vessel size categories in the 2006-2011 period. Data is referred to the selected FU in the study (1 kg of landed fish).

Inputs	**Unit**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Diesel	l	0.03 (0.09)	0.00 (0.11)	0.02 (0.14)	0.03 (0.12)	0.03 (0.09)	0.02 (0.10)
Ice	kg	0.02 (0.11)	0.02 (0.08)	0.04 (0.12)	0.05 (0.12)	0.05 (0.15)	0.05 (0.18)
Marine lubricant oil	l	0.00 (0.00)	0.00 (0.00)	0.01 (0.01)	0.02 (0.01)	0.01 (0.01)	0.01 (0.00)
Outputs							
Sardine	kg	0.70 (0.91)	0.89 (0.89)	0.90 (0.91)	0.88 (0.94)	0.95 (0.89)	0.93 (0.85)
Other species	kg	0.30 (0.09)	0.11 (0.11)	0.10 (0.09)	0.12 (0.06)	0.05 (0.11)	0.07 (0.15)
CO2	kg	0.29	0.36	0.47	0.40	0.30	0.32
SO2	g	0.43	0.52	0.66	0.57	0.44	0.46
NOx	kg	3.0E-03	4.0E-03	5.0E-03	4.0E-03	3.0E-03	3.0E-03
Impact assessment							
GWP	kg CO2 eq.	2.92E-02	3.63E-01	4.66E-01	3.97E-01	3.01E-01	3.18E-01
EP	kg PO4 eq.	4.42E-04	5.50E-04	7.04E-04	6.01E-04	4.56E-04	4.81E-04
AP	kg SO2 eq.	1.99E-03	2.47E-03	3.16E-03	2.70E-03	2.05E-03	2.16E-03
ODP	kg CFC-11 eq.	3.86E-09	4.75E-08	6.04E-08	5.18E-08	3.97E-08	4.18E-08
E	MJ	4.33E+00	5.39E+00	6.91E+00	5.90E+00	4.47E+00	4.72E+00

Appendix 2

Table II Values of impact categories for the total and the life cycle phases for one can of sardines in olive oil (120g of edible product). The other packaging phase includes a board box and the secondary packaging.

Impact category	Unit	Total	Sardine	Salt	Olive oil	Can	Other packaging	Canning	Transports
ADP	kg Sb eq	2.3E-03	4.2E-04	1.3E-05	x	1.2E-03	1.2E-04	5.0E-04	1.9E-05
AP	kg SO_2 eq	4.6E-03	4.2E-04	1.6E-05	6.8E-04	3.1E-03	8.5E-05	3.2E-04	1.3E-05
CED	MJ	6.1E+00	9.5E-01	2.8E-02	7.6E-02	3.2E+00	7.8E-01	1.0E+00	3.9E-02
EP	kg PO4--- eq	1.4E-03	9.3E-05	7.9E-07	6.1E-04	4.5E-04	3.5E-05	1.8E-04	2.9E-06
GWP	kg CO_2 eq	9.0E-01	6.4E-02	2.4E-03	1.0E-01	6.4E-01	1.6E-02	7.2E-02	2.8E-03
ODP	kg CFC-11 eq	5.4E-08	7.4E-09	x	3.0E-08	1.4E-08	1.5E-09	1.4E-09	2.6E-12
METP	kg 1.4-DB eq	5.2E-01	1.1E-02	4.6E-06	4.7E-02	4.2E-01	1.9E-02	1.7E-02	5.9E-05
POCP	kg C_2H_4 eq	2.9E-04	6.8E-06	6.3E-07	1.3E-04	1.4E-04	3.8E-06	9.6E-06	3.2E-07

Table III Comparison of the impact categories for 1 kg of edible product of sardines canned in olive oil, fresh and frozen.

Impact category	Unit	Frozen	Fresh	Canned
ADP	kg Sb eq	1.4E-07	6.1E-08	2.5E-06
AP	kg SO_2 eq	6.2E-03	4.4E-03	3.8E-02
CED	MJ	1.6E+01	1.2E+01	5.2E+01
EP	kg PO4--- eq	1.4E-03	9.6E-04	1.2E-02
GWP	kg CO_2 eq	9.7E-01	7.3E-01	7.7E+00
ODP	kg CFC-11 eq	9.4E-08	8.3E-08	4.6E-07
METP	kg 1.4-DB eq	1.5E+03	1.3E+03	1.5E+04
POCP	kg C_2H_4 eq	1.4E-04	2.3E-04	2.5E-03

Appendix 3

Elaborated questionnaire on the seafood consumption, knowledge and information interest of the Portuguese consumers (four sections).

1. Frequency of consumption

For each of the following types of seafood meals could you please indicate how often you ate it during the last year?

	Never	1	2-11	1	2	3	1	2	3	4	5	6	7
		Times a year		Times a month			Times a week						
Seafood (in general)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Seafood for dinner at home	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Seafood for lunch at home	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Seafood for dinner out of home (e.g. restaurant)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Seafood for lunch out of home (e.g. restaurant)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Boiled seafood	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Grilled seafood	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fried seafood	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Baked seafood	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Seafood prepared in another way	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

For each of the following seafood species could you please indicate how often you ate it during the last year?

	Never	1	2-11	1	2	3	1	2	3	4	5	6	7
		Times a year		Times a month			Times a week						
Mussles	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Tuna	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Octopus	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Horse mackerel	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sardine	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cod	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cockle	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Salmon	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sea-bream	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Shrimp	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sea-bass	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Clams	◻	◻	◻	◻	◻	◻	◻	◻	◻	◻	◻	◻	◻
Hake	◻	◻	◻	◻	◻	◻	◻	◻	◻	◻	◻	◻	◻
Chub mackerel	◻	◻	◻	◻	◻	◻	◻	◻	◻	◻	◻	◻	◻
Other													

To what extent are you responsible for food shopping in your household?

Not responsible at all	Responsible for less than half	Responsible for about half	Responsible for more than half	Responsible for all
◻	◻	◻	◻	◻

To what extent are you responsible for cooking and preparing the food in your household?

Not responsible at all	Responsible for less than half	Responsible for about half	Responsible for more than half	Responsible for all
◻	◻	◻	◻	◻

2. Knowledge

For each of the following statements, could you please indicate the extent to which you agree or disagree with it using the full scale from "Totally disagree" to "Totally agree". You can use the in-between scores to shade your opinion.

	Totally Disagree						Totally Agree
Compared to an average person, I know a lot about fish and other seafood	◻	◻	◻	◻	◻	◻	◻
My friends consider me as an expert on fish and other seafood	◻	◻	◻	◻	◻	◻	◻
I have a lot of knowledge of how to prepare fish and other seafood for dinner	◻	◻	◻	◻	◻	◻	◻
I have a lot of knowledge of how to evaluate the quality of fish and other seafood	◻	◻	◻	◻	◻	◻	◻

In your opinion, are the following statements true or false?

	TRUE	FALSE
Salmon is almost exclusively farmed	◻	◻
Fish is a source of omega-3 fatty acids	◻	◻
Cod doesn't exist in the Portuguese coast	◻	◻
Salmon is a fatty fish	◻	◻
All fish stocks are overexploited	◻	◻
At least two servings of oily fish per week is the recommendation for a healthy eating	◻	◻
The eyes of the fish don't demonstrate its freshness	◻	◻

3. Information interest

Please indicate to what extent you are interested in the following information (appearing on the package/shelf) when you buy seafood, using the full scale from "not at all interested" to "Very interested". You can use the in-between scores to shade your opinion.

	Not at all	Very

	interested						Interested
Method of preparation (how to prepare the fish)	☐	☐	☐	☐	☐	☐	☐
Wild / farmed	☐	☐	☐	☐	☐	☐	☐
Health benefits	☐	☐	☐	☐	☐	☐	☐
Recipes (sugestions to cook)	☐	☐	☐	☐	☐	☐	☐
Catch origin (e.g. country, region)	☐	☐	☐	☐	☐	☐	☐
Quality mark	☐	☐	☐	☐	☐	☐	☐
Catch method (e.g. line, trawl)	☐	☐	☐	☐	☐	☐	☐
Sustainable fisheries (e.g. MSC)	☐	☐	☐	☐	☐	☐	☐
Fish welfare	☐	☐	☐	☐	☐	☐	☐
Feed used during farming	☐	☐	☐	☐	☐	☐	☐
Catch date	☐	☐	☐	☐	☐	☐	☐
Fresh / Frozen	☐	☐	☐	☐	☐	☐	☐
Processed origin (e.g. country)	☐	☐	☐	☐	☐	☐	☐
Expiry date	☐	☐	☐	☐	☐	☐	☐
Colorants used	☐	☐	☐	☐	☐	☐	☐
Price	☐	☐	☐	☐	☐	☐	☐
Genetically modified	☐	☐	☐	☐	☐	☐	☐
Minium size of capture alloweded	☐	☐	☐	☐	☐	☐	☐

4. Socio-demographic information

Are you female or male?	☐	Female	☐	Male		
Birth data?	...	Year				
Place of birth?	...	Country				
Residence?	...	Country	...	Region		
What is your last completed education?	Basic	Technical highschool	Additional technical training	BSc (or similar)	MSc (or similar)	PhD (or similar)
	☐	☐	☐	☐	☐	☐
What is your current occupation?	Unemployed	Employed	Self employed	Responsible for the household	Student	Retired
	☐	☐	☐	☐	☐	☐
Do you work...	☐	Full time	☐	Part time		
What is your current marital status...?	Single (never married)	Married	Separated	Divorced	Living together	Widowed
	☐	☐	☐	☐	☐	☐
How many people are living in your household, including yourself?	...	People.				
Do you live with your parents?	☐	YES	☐	NO		
How many children from the following age categories live in your household?	0-5 years old	6-10 years old	11-15 years old	16 years old or over		
	☐	☐	☐	☐		
Would you say you live in a ...?	Rural area or village	Small or middle sized town	Large town			

<table>
<tr><td></td><td colspan="3">☐</td><td colspan="3">☐</td><td colspan="2">☐</td></tr>
<tr><td>Do you live …?</td><td colspan="4">On the seaside (less than 50 km from the coast)</td><td colspan="4">Inland (more than 50 km from the coast)</td></tr>
<tr><td></td><td colspan="4">☐</td><td colspan="4">☐</td></tr>
<tr><td>What is the present total monthly income (after tax) in your household?</td><td><500€</td><td>501-1000€</td><td>1001-1500€</td><td>1501-2000€</td><td>2001-2500€</td><td>2501-3000€</td><td>>3000€</td><td>não sabe/ não responde</td></tr>
<tr><td></td><td>☐</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td></tr>
</table>

Appendix 4

Survey subjective and objective knowledge question responses. Bolded score indicates the correct answer.

Subjective knowledge about seafood	**Mean (SD)**	**Totally disagree 1**	**2**	**3**	**4**	**5**	**6**	**Totally agree 7**	**Blank**
Compared to an average person, I know a lot about fish and other seafood	4.4 (1.7)	69	138	146	323	192	184	181	7
My friends consider me as an expert on fish and other seafood	3.2 (1.9)	335	220	161	223	114	85	96	6
I have a lot of knowledge of how to prepare fish and other seafood for dinner	3.7 (1.7)	163	177	208	267	218	111	89	7
I have a lot of knowledge of how to evaluate the quality of fish and other seafood	3.8 (1.8)	137	206	204	225	200	144	117	7

Objective knowledge	**False (%)**	**True (%)**	**Blank**
Salmon is almost exclusively farmed	282 (22.7)	**944 (76.1)**	14
Fish is a source of omega-3 fatty acids	61 (4.9)	**1170 (94.4)**	9
Cod doesn't exist in the Portuguese coast	322 (26.0)	**913 (73.6)**	5
Salmon is a fatty fish	98 (7.9)	**1135 (91.5)**	7
All fish stocks are overexploited	**685 (55.2)**	532 (42.9)	23
At least two servings of oily fish per week is the recommendation for a healthy eating	329 (26.5)	**895 (72.2)**	16
The eyes of the fish demonstrate its freshness	100 (8.1)	**1126 (90.8)**	14